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ONTARIO

DEPARTMENT OF LABOUR

MINISTER

THE HONOURABLE CHARLES DALEY

REFRIGERATION AND AIR COMPRESSION

OPERATING ENGINEERS BOARD

TORONTO
Printed by T. E. BOWMAN, Printer to the King's Most Excellent Majesty
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Parliament Buildings, East Block

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AIR COMPRESSION

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PREFACE

This book on Refrigeration and Air Compresion is the fourth of a series prepared by the Board.

The complete series to date comprises six books dealing with the following subjects: Boilers, Engines, Turbines, Condensers and Pumps, "A Beginner's Book on Power Plant Operation," Refrigeration and Air Compression, Combustion, Steam Plant Accessories.

It need hardly be stated that these text-books are not entirely original. Material gathered from magazines and catalogues has been freely used, with the view of supplying the latest information to the student.

In these days when power plant operation is constantly widening its field, a knowledge of refrigeration is imperative. The purpose of the present book is to stimulate the engineer to acquire this knowledge.

There is a high standard of power plant engineering in Ontario. Let us maintain this standard and in so doing advance employee and employer alike.

THE BOARD OF EXAMINERS
OPERATING ENGINEERS,
East Block, Parliament Buildings,
Toronto, Ontario.

REFRIGERATION

To the beginner there is something of mystery about refrigeration and how it is possible to make ice on a summer day. The matter simplifies itself in certain phenomena of nature, which man has been able to use to his advantage, are considered.

These may be listed as:

(1) A liquid cannot become a gas unless it absorbs heat which does not raise its temperature. For instance, water in a tea kettle will rise in temperature till it reaches 212 degrees, but afterwards does not get any hotter, no matter how great the fire is under it. The only change that takes place is that the water turns to steam.

(2) A gas cannot become liquid unless it gives off heat which does not lower its temperature. For instance, steam in a radiator may heat a room by turning to water but the temperature of the water will be just the same as the steam.

(3) A liquid will not convert to a gas as readily when under pressure, but requires a higher temperature than it does if not under pressure. For instance, the water in a tea kettle will start to boil when a temperature of 212 degrees is reached, but the water in a boiler carrying 150 pounds pressure will not boil until a temperature of 366 degrees is reached.

So far we have only discussed water and steam, but the same laws are equally true of ammonia liquid and ammonia gas. The only difference is that ammonia liquid boils at a very much lower temperature than water. For instance, water in the open air will boil at 212 degrees while ammonia liquid will boil in the open air at zero weather and it is equally true that to liquefy ammonia gas under atmospheric pressure, we would require at least 28 below zero weather.

Of course, as we mention in (3), if the pressure is increased on the ammonia gas it will liquefy at a higher temperature. For instance, at 150 pounds pressure the gas will convert to a liquid at a temperature of about 78 degrees.

In the process of refrigeration the ammonia gas is first made to liquefy, then boil, then liquefy, then boil, et cetera, as long as the plant is in operation. Let us bear in mind that when it boils, it must take heat from somewhere and when it liquefies, it must give off heat.

We will follow the course of the ammonia through the refrigerating system. The gas flows to the compressor and is compressed to a pressure of about 150 pounds and forced into the condenser. In the condenser the pressure will, of course, be about 150 pounds. Now, as we said before, when ammonia gas is under a pressure of 150 pounds, it will liquefy at a temperature of 78 degrees, therefore, if water at a temperature of say 70 degrees or less is circulated through pipes in the condenser, the gas will liquefy and will give off its latent heat to the water, and this heat will be carried off to the sewer.

The liquid ammonia in the condenser is then allowed to flow out through a small pipe to the expansion coils. On this pipe is a valve which controls the amount of liquid passing. As soon as the liquid passes this valve the pressure is greatly reduced, with the result that the liquid boils and reverts again to a gas. As we have already stated, the liquid cannot turn to a gas without absorbing heat. It therefore absorbs heat from the surrounding atmosphere of the room and as the room is robbed of its heat, it naturally becomes colder, or, if the coils are placed in a brine tank, the brine is robbed of its heat. When the ammonia has absorbed sufficient heat to be converted to a gas, it flows back to the compressor and the operation is repeated.

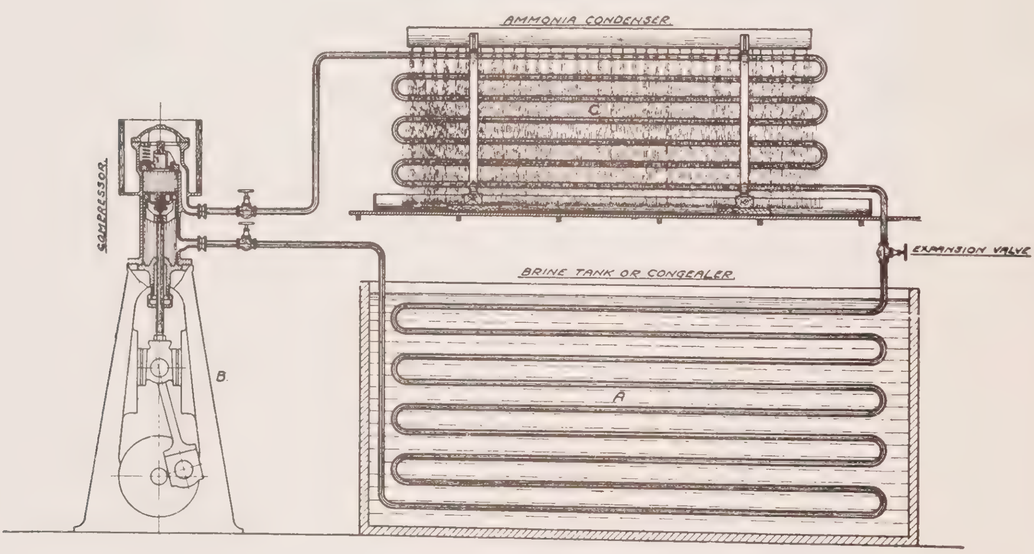


Fig. 1. Simple sketch showing circuit of ammonia through refrigeration system.

The simplest form of refrigerating apparatus would consist of three principal parts as shown in Fig. 1.

A is a brine tank, or, as it is sometimes called, the "congealer," in which the ammonia is vaporized and the refrigeration produced. This could have been represented by a refrigerator box, in which case the cooling coils would cool the air in the box instead of the brine in the tank.

B is the ammonia compressor which is a combined suction and pressure pump, pumping the ammonia gas from the cooling coils as fast as it is formed and delivering it into the condenser.

C is an ammonia condenser consisting of a pipe coil into which the ammonia gas is discharged by the compressor at high pressure and changed back to its liquid state by means of cooling water flowing over it.

Referring to Fig. 1, the apparatus is first charged with a sufficient quantity of the cooling medium, which is stored in the lower part of the condenser C. A small cock or expansion valve in the pipe leading to the congealer or brine tank A is opened slightly, allowing the liquid to pass into the evaporator coils. These coils perform the same office as the tubes or flues in a steam boiler, and may, with equal propriety, be named the heating surface.

The amount of water converted into steam in a boiler depends on the number of square feet of heating surface, the temperature of the fire and the resulting pressure which the steam exerts. The same is true of the capacity of the heating or heat-robbing surface of the coils in the evaporator. The heat is transmitted through these coils, being taken from the substance surrounding them and absorbed by the refrigerating medium. This heat causes the refrigerating medium to boil and creates a vapour, just as water when boiling gives off steam.

As previously explained, the surrounding substance parts with an equivalent amount of heat and thus becomes cooler, this heat being transferred to the cooling medium where it is taken up and absorbed in proportion to the pounds of liquid evaporated. The quantity of liquid evaporated is under the control of the expansion valve, which must be regulated to suit the capacity of the compressor under working condition.

As the gas begins to form in the evaporator the compressor pump B is set in motion at such speed as to carry away the gas as fast as it is formed. This is discharged into the condenser under such pressure and temperature as will bring about condensation and restore the gas to its liquid state, ready again to pass through the expansion valve. This constitutes the refrigerating cycle, which is continuous so long as the compressor is kept in operation and the proper quantity of water is circulated over the condenser. The condenser water absorbs the heat of compression and the heat that the refrigerant has absorbed in the evaporator.

Properties of Ammonia

Pure anhydrous ammonia is supplied in strong iron cylinders in liquid form. It is colorless, has a pungent alkaline odor and one cubic foot of the liquid weighs approximately forty pounds.

At ordinary atmospheric temperatures it exerts a pressure of about 150 pounds on the cylinder and if the cylinder is opened and the pressure relieved the liquid ammonia will immediately expand into a gas.

When a liquid passes to a gaseous or vapor state a certain amount of heat is required to bring about the change. As the heat is absorbed during the process of vaporization it

is called the latent heat of vaporization, and the science of refrigeration is based on this natural law.

The latent heat of ammonia is about 565 heat units at atmospheric pressure, that is, each pound of liquid ammonia will take up 565 heat units from surrounding objects when it changes into a gas at atmospheric pressure.

The boiling point of water is 212° Fahrenheit at atmospheric pressure. The boiling point of pure liquid ammonia at atmospheric pressure is about 27° Fahrenheit below zero.

If you place an open glass of ammonia liquid in a bank of snow it will absorb enough heat from the snow to boil, while on the other hand a fire will be required to boil the water.

Note: We are speaking of pure ammonia which has been liquefied, and not of aqua ammonia which can be bought at the local drug store and which is ammonia gas that has been absorbed in water.

It is these physical properties of ammonia, namely the fact that it is a liquid at ordinary temperature and about 150 pounds pressure, and that it boils off into a gas at atmospheric pressure and very low temperature, together with the fact that it is readily manufactured and can be procured at a nominal cost, which make it such an ideal refrigerating liquid.

Care of Small Refrigerating Machines

Common difficulties occurring in the operation of refrigerating machines, their causes and remedies, are given in tabular form, and are fully explained in the text following the numbered paragraphs.

Ammonia Compressor Troubles, Their Cause and Correction

Trouble	Cause	Remedy
1. Too high condensing pressure.	Too little or too warm condensing water.	Supply more or cooler water to condenser.
2. Too high condensing pressure.	Condenser coils fouled with scum or scale.	Scrape condenser coil clean.
3. Very high condensing pressure, trembling of the pressure, gauge and condenser pipe. Temperature corresponding to the pressure considerably higher than the condensing water discharge temperature.	The presence of air or non-condensable gases in the system or too great a charge of refrigerant.	Blow-off air or non-condensable gases. Take ammonia out of the system.
4. Too low condensing pressure.	Too small a charge of gas.	Add ammonia to the system.
5. Rapid fall of suction pressure, increase of condenser pressure.	Expansion valve closed or open too little.	Gradually open expansion valve till correct condition is obtained.
6. Too high suction pressure. Discharge connection cold. Heavy frost on compressor.	Expansion valve too wide open.	Gradually close expansion valve till correct condition is obtained.
7. Loud hammering of compressor valve.	Broken spring on compressor valve.	Put in new spring.

8. Irregular action of compressor valve.	Dirty or leaky compressor. valve.	Overhaul valves.
9. Capacity of compressor reduced.	Leaky piston.	Overhaul piston and cylinder.
10. Stuffing box and discharge pipe too hot.	Expansion valve closed or open too little.	Open expansion valve wider very slowly.

(1) The correct amount of condensing water is about three gallons per minute, per ton of refrigerating capacity of the machine, with a 9 degree range of temperature of water flowing to and leaving the condenser.

To determine whether the condenser pressure is too high, reference must be made to an ammonia table giving the properties of saturated ammonia gas.

It will be noticed that for every temperature of the gas, there is a corresponding pressure. Assume that the temperature of the condensing water leaving the condenser is 70 degrees F. The high-pressure gauge should show a pressure corresponding to 8 or 10 degrees higher, or about 80 degrees F., which is 139.40 pounds.

If the pressure shown on the gauge is higher than this, the causes given in the table should be investigated.

(2) If a double-pipe condenser is used, examination of the water pipe which is the inner pipe, should be made to see that it is not clogged with slime or incrusted with scale. The surface of atmospheric condensers should be examined for the same conditions. Double pipe condensers should be located in as cool a place as possible.

Atmospheric condensers should be placed so that they are protected from the direct rays of the sun and so that they will get the benefit of the prevalent summer winds. The wind will cause some of the condensing water to evaporate and thus cool the rest of the water with a resultant lowering of the condenser pressure.

In some localities the wind is so strong that it will blow the water off the condenser, resulting in increased pressure. To avoid this and to protect the condenser from the direct rays of the sun, a slatted housing is sometimes built over the condenser which allows the wind to enter but breaks its force.

(3) Before deciding that air or non-condensable gases are present in the system, the operator should be thoroughly satisfied that the excessive pressures are not due to the causes mentioned in (1) and (2) of the table, because too frequent purging is one of the greatest sources of high ammonia consumption and waste.

It is customary to purge by having a valve connection at the top of the condensers from which a connection can be run to a pail of water. As long as bubbles can be seen rising, non-condensable gases are being discharged. When ammonia starts to blow off water absorbs it, the bubbles stop and a crackling sound can be heard. The purging valve should be closed immediately when this occurs.

If there is too much refrigerant in the system, the gauge-glass on the liquid receiver will show too high a level. The correct level when the plant is in operation and doing its greatest amount of refrigeration, should be specified by the manu-

facturer who installs the machine. Ordinarily, from 25 to 30 pounds of ammonia is required per ton of refrigeration.

To reduce the amount of refrigerant in the system, a connection should be made from the drain pipe on the liquid receiver to an empty ammonia tank and the liquid allowed to drain out until the proper amount is present. Care should be taken not to fill the ammonia shipping tank too full. Do this by weighing it as the liquid receiver is drained.

(4) Reference to the ammonia table and inspection of the gauge-glass on the liquid receiver will determine whether this trouble exists. Ammonia should be added through the charging valve of the system, care being taken not to add too much.

(5) The condition under (5) of the table causes inefficient operation because it results in the gas being superheated instead of saturated. Saturated gas is gas in contact with its liquid, and its volume per pound for a particular pressure corresponds to that given in the ammonia table for that pressure. Superheated gas is gas not in contact with its liquid and occupies a greater volume per pound than that corresponding to its pressure. For example, we see, by reference to the ammonia table, that at 15.7 lb. pressure a cubic foot of vapor weighs 0.1097 lb., or that a pound of ammonia vapor has a volume of 9.116 cubic feet when saturated. If superheated, it will have a greater volume than this per pound, depending on the amount of superheat. This superheat is due to the difference in temperature between the gas, which is cold, and the rooms through which the suction pipe passes, which are comparatively warm. Because of this difference in temperature, the gas is heated, therefore its volume increases. If liquid were present this heat which leaks in would simply supply the latent heat required to evaporate the liquid instead of heating the gas and thus increasing its volume.

With superheated gas, therefore, the compressor pumps a smaller weight of gas per revolution with resultant falling off in capacity.

Under the usual operating temperature correct conditions will show frost on suction line just up to the compressor, indicating the presence of liquid, and the discharge pipe will be fairly hot to the hand.

(6) The conditions under (6) of the table, cause inefficient operation because they result in liquid returning to the compressor. If liquid is coming back it will evaporate on the suction stroke and prevent gas from being drawn into the compressor, reducing its capacity. Also, liquid coming back will cool the stuffing-box, cause the packing to contract, and leakage of gas will occur. Do not tighten up on the stuffing-box, but close the expansion valve somewhat until the liquid stops coming back.

Where a load on the refrigerating machine varies frequently, it is difficult to pack a rod tight, because, part of the time, when the load is light, liquid may come back, which causes contraction of the packing and leakage. At other times, when the load is heavy, gas comes back superheated, the packing expands and friction is greatly increased, because an ammonia stuffing-box is comparatively deep. This friction increases the power consumption and will carbonize the packing.

With a varying refrigerating load as described, if a stuffing-box is tightened when liquid is coming back, it should be slacked off when the suction is dry. Close attention to and regulation of the expansion valve will eliminate a large amount of stuffing-box trouble.

The adjustment of a stuffing-box is a matter of experience with the particular installation to be taken care of.

When the expansion valve is too wide open, the compressor shows too much frost and the discharge line is cold to the touch.

(7, 8) (& 9) To make these repairs to valves, et cetera, it is necessary either to pump out the compressor or to close both the main suction and discharge valves and to allow the ammonia to escape, either through the valve provided on some compressors, or through an open joint.

To pump out the compressor, close the main liquid valve and then the suction valve. Run the compressor for a few minutes. Stop it quickly and close the discharge valve tight. The by-pass valve from the discharge line to the suction line should then be opened and closed quickly, or the compressor may again be started with the by-pass open and the suction and discharge valves closed and run a short period until a vacuum is created.

The machine should then be stopped and the by-pass closed immediately. The valve for the purpose of allowing ammonia to escape from the compressor can now be opened, or, if such a valve is not provided, a joint can be slowly loosened, but care should be taken, as a pressure is liable to be built up again in the cylinder. The compressor can now be taken apart for inspection and repairs.

(10) See 5.

INSTRUCTIONS FOR OPERATING SMALL AMMONIA MACHINES

Different types of refrigerating machines have different characteristics, but the following instructions will, in general way, fit into the operation of all machines.

To Start Machine

Never close discharge valve.

Before starting machine, make **sure** to open supply valve to ammonia condenser and machine water jackets. Water valve controls the pressure shown on high pressure ammonia gauge. Gauge should read between 125 and 150 pounds, while machine is in operation. If below 125 pounds, shut off a little water. If above 150 pounds, turn on a little more water. By regulating water valve as stated, proper pressure can be obtained.

After water has been turned on condenser, start machine and open valve called suction valve, as soon as possible.

After suction valve has been opened, low pressure gauge will start to go back towards 0 pounds. When it reaches about 15 pounds on gauge, open up expansion valve. Care must be taken not to open this valve **too much,** as it would cause machine to frost. Valve

should be regulated so that frost just reaches machine. If machine should become frosted, shut off expansion valve a little, and in a short time, frost will disappear.

After machine has been operating for a short time, if necessary, regulate expansion valve so as to bring frost up to scale trap at machine.

Don't frost up machine.

Don't try to hold any given pressure on suction gauge—this will vary according to temperature of brine or room, if frost is carried just up to machine.

To Shut Down Machine

Close expansion valve.
After closing expansion valve, close suction valve.
After closing suction valve, machine should be shut down *as soon* as possible.
Shut down machine. Close water valve.

If condensers are placed in room which may be colder than freezing, during the winter, care must be taken to see that all water lines on condenser and machine water jackets, are drained out after every operation, as there is *danger* of same freezing and bursting pipe. A necessary drain is provided for machine water jacket and condenser.

Instructions for Charging Oil

Shut suction valve, start machine running until a vacuum is created in crank case, which will happen after machine has made a few revolutions, then place end of hose attached to oil connection on machine in pail of oil, then open oil valve. Do not allow end of hose out of oil, but shut off oil valve before pail is empty, so as to make sure not to suck in any air. Fill oil chamber to height marked on small brass plate near glass. Be sure oil is **perfectly clean** and contains no grit, before placing in crank case.

To Pack Stuffing Box on Machine

Shut off suction valve. Allow machine to run a few revolutions, then shut down machine and shut off discharge valve. After this has been done, open up oil valve where hose is attached and if you find vacuum it is safe to take off stuffing gland. Take out old packing and replace with new. Always *make sure to open* up discharge valve *before starting machine*. Never tighten packing while machine is running more than just enough to avoid ammonia smell.

Charging System with Ammonia

Referring to Fig. 2 to charge the system.

It is always well to place the charging drum on a set of scales, with the back end raised on a block and weighed.

Be sure the bent pipe inside the cylinder is facing down. This will usually be the case if the valve opening is facing up.

Now connect the drum to the charging valve of the machine with a suitable bent pipe.

While the machine is running and condenser water flowing, close the king valve and reduce the pressure in the evaporating coils to zero or slightly below. Then open the charging valve and also open the valve on end of charging cylinder very slowly and make sure there are no leaks.

It is well to note that the packing gland of this valve has a left hand thread and must be turned in the opposite direction to the ordinary valve to tighten.

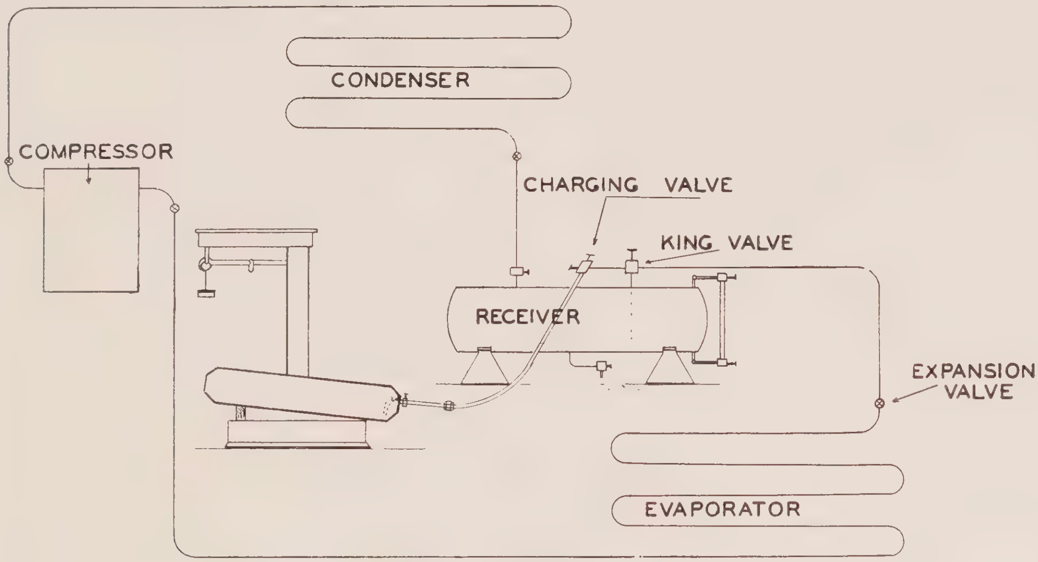


Fig. 2. Diagram showing method of charging system with ammonia.

If it is not desirable to put the full quantity of ammonia in the cylinder into the system, the scales should be set at the weight required and he valve closed when the scales balance.

If the drum is to be completely emptied the scales may be dispensed with and pumping continued until frost appears on the bottom of the cylinder and up the pipe to the charging valve.

Having completed the charging, close the valve on the cylinder and then the charging valve, and open the king valve. The drum may now be disconnected. Care should be taken, however, as a pressure may build up in the pipe.

Ordinarily, from 25 to 30 pounds of liquid ammonia are required per ton of refrigeration.

Pumping Out Condenser

If for any reason, such as to repair a leak, it is found necessary to empty the condenser of ammonia, it may be accomplished as follows:

While the machine is shut down, close the valve between the condenser and the receiver; close the suction and discharge valves; open the cross-over by-pass valves.

Now start up machine and owing to the by-passes, the direction of flow of ammonia gas will be reversed and will therefore be drawn from the condenser and forced into evaporating coils. This process would be continued until a vacuum shows on the condenser gauge. Then shut down, but, if pressure again shows on the gauge, start machine and run until sure that all gas has been removed.

While pumping out the condenser, care should be taken that the cooling water be turned on full or completely shut off and condenser drained, for, owing to reversing the system, the condenser becomes the evaporating coils and the ammonia liquid evaporating would cause the water to freeze.

Also, care should be taken that the oil trap on the discharge pipe is drained, otherwise the oil may be drawn back into the compressor.

Also, since the evaporating coils under this reversed condition now becomes a condenser and as there is no cooling water, care must be taken that a high pressure is not allowed to build up in these coils. Furthermore, if the evaporating coils should be coated with ice, the heat from the ammonia will loosen this ice from the pipes and as it drops off in pieces may damage any goods in the vicinity.

De-frosting Pipes

By the way, the above is a method of de-frosting the evaporating pipes when the ice becomes so thick that it interferes with the free transfer of heat from the room to the coils. The ice having become loosened from the pipes due to the heat, can be broken and knocked down with a hammer.

Danger Connected with the Operation of Refrigerating Machinery

As a rule, an industry in which chemicals and highly-compressed gases are used in connection with tanks, pipes and moving machinery, is quite likely to involve a considerable accident hazard and mechanical refrigeration is by no means an exception to this. Safety in connection with mechanical refrigeration may be divided into two phases: (1) safety in operation and (2) safety in case of accident to the apparatus or in case of fire.

Provision of safety-valves on certain parts of the apparatus operating under high pressure, and also some provision for getting rid of all the ammonia in the apparatus in case any break occurs in the circulating system, or in case of fire, should be made. (See Figs. 15 and 16.)

When a refrigerating system is first installed, it is customary to test it out with air pressure before it is charged with ammonia.

This practice is commendable if properly done, but it may result disastrously if done in a careless way. Explosions sometimes occur during such tests, and these are commonly attributed to the ignition of the lubricating oil used in the compressor. Never allow the compressor to get too highly heated during such a test, and do not use an excessive amount of oil. Keep away from the apparatus as much as possible, because an unforeseen weak-

ness or imperfect joint may cause a failure of some part. Remember that it has not yet been shown that such weaknesses or imperfections do not exist. The test is being made for the purpose of settling this question.

Leaks in any part of the ammonia system often lead to serious results, because a mixture of air, ammonia, hydrogen, oil vapor and other volatile impurities may ignite and cause a violent explosion.

There is no danger of such mixtures exploding, however, unless heat is applied, or they are brought in contact with a flame or spark.

All arc lights and other open flames should be eliminated in rooms where the apparatus is installed, and self-closing doors should be provided, separating other parts of the building from the rooms where leaks are likely to occur. It is also imperative to provide some means of ventilating rooms in which leaks may occur and the ventilating equipment should be so arranged that it can be operated from outside the room.

The greater danger associated with the use of ammonia consists in the harmful effect of the gas on persons breathing it.

Special ammonia gas masks are available, but they are not highly efficient when the gas is concentrated and for that reason, oxygen helmets are the only safe and practical respiratory apparatus that can be used by persons who have to enter a room filled with strong ammonia gas. Oxygen respirators should be provided in all refrigerator rooms, and at least one such apparatus should be kept in some place outside the room, where it will be available for use in case it becomes impossible to enter the room and obtain the respirator there.

In operating the expansion valves on compression or absorption systems, the engineers should be careful not to allow too much liquid in the coils at one time.

Considerable experience is required in operating these feed valves. In compression systems the outlets of the coils should be watched constantly to see that liquid is not allowed to pass over and into the compressors. If an appreciable amount of liquid gets into the compressor cylinders, it is likely to do considerable damage by cracking the cylinder head, or bending the piston rod. Liquid ammonia is incompressible and acts in much the same way as water in the cylinder of a steam engine.

Carelessness in charging the ammonia system often results in serious consequences. The charging should be done only through proper pipe connections located near the expansion valve and on the low pressure side of it.

In apparatus in which the charging cylinder is attached to the liquid line, if the main (or "king") valve on the liquid line is not closed when the charging cylinder is attached, the pressure on the line may be greater than that in the cylinder, and consequently, ammonia from the system would flow into the cylinder, filling it completely.

If such a cylinder were heated, even slightly, after its stop-valve were closed, the pressure in it would rise very rapidly and the cylinder itself would be likely to burst. To be sure that liquid has not passed into the charging cylinder, every such cylinder should be weighed before and after charging has been done. The difference in weight will indicate the amount of ammonia that has been put into the system. The charging cylinders should

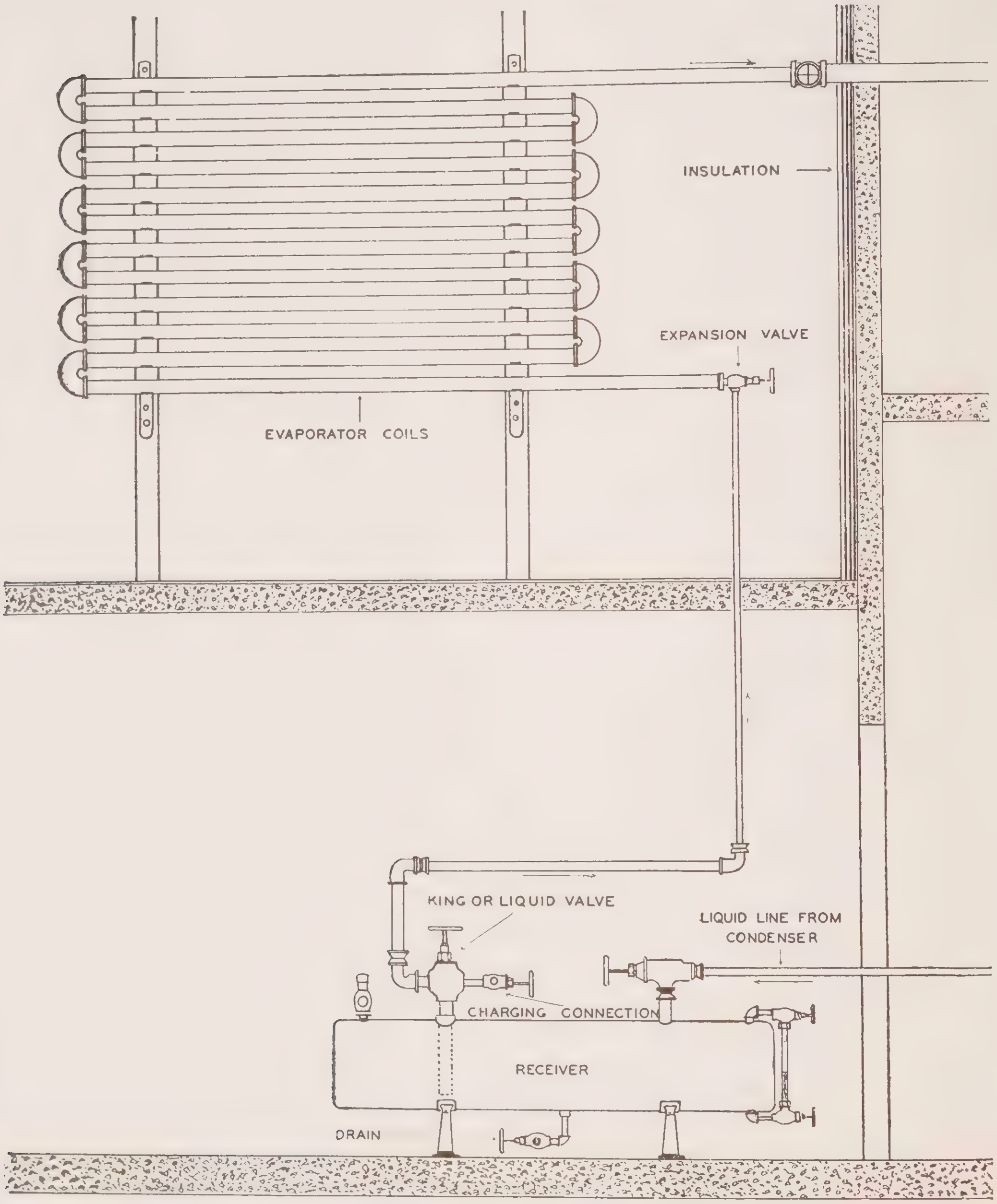
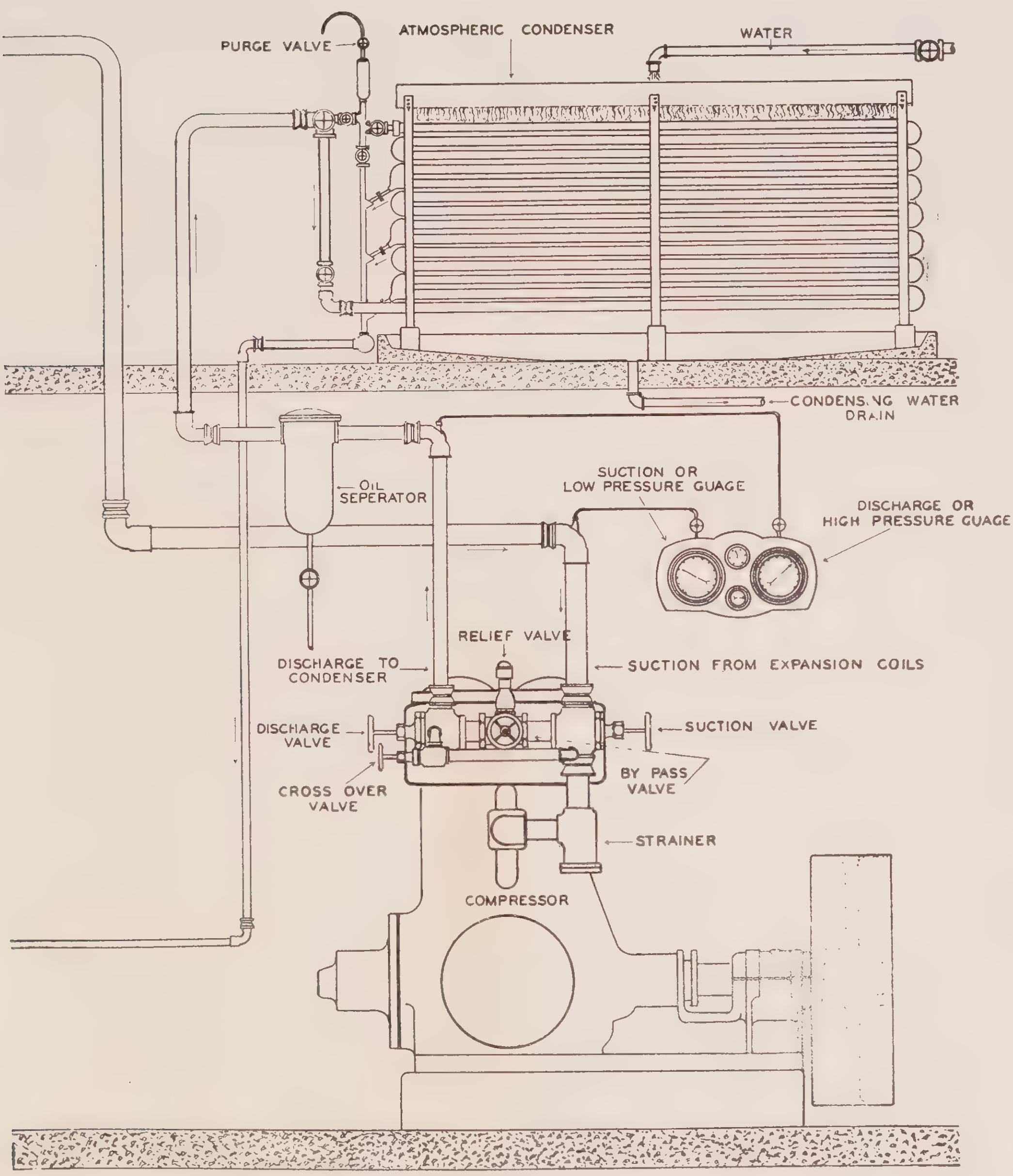


Fig. 3. Diagrammatical sketch of a refrigerating



plant showing its component parts.

be detached from the system as soon as the charging operation is completed and all cylinders should be stored in a cool place.

Many of the valves on the various pipe lines and tanks are seldom used, but they should be regularly inspected and tested to make sure they are in working order.

An accumulation of rust in the stuffing-boxes or on the threads might easily make it impossible to operate the valves, and this would be highly important if an emergency should arise.

The design of the valves used on refrigerating apparatus is particularly important and it must be remembered that special valves are absolutely necessary for the safe operation of the systems. Valve accidents are not uncommon and it is evident that care in the selection of materials, together with careful attention to the installation and upkeep, are essential in reducing these accidents to a minimum.

The installation of safety-valves to prevent excess pressure, is highly important on those parts of the refrigerating equipment that are operated under high pressure. The ammonia escaping from these safety-valves may be discharged through proper pipe connections into the low-pressure side of the apparatus, or, the gas may be conducted away from the refrigerating machine and discharged into the air, or into a tank of water.

When discharging into the air, the ammonia should be conducted by continuous piping to a point above the roof of any building within 50 feet of the valve and then discharged through a diffusing device, designed to thoroughly mix the gas with the air. If the ammonia is discharged into a tank of water, the capacity of such tanks should be great enough to provide at least one gallon of water for every pound of ammonia contained in the equipment and this amount of water should be automatically maintained within the tank.

It is evident, therefore, that the use of water for collecting the escaping gas would be practicable only for systems containing up to a thousand pounds of refrigerant. When water is used, some provision should be made for keeping it at a temperature above 32 degrees Fahr., to prevent freezing.

Every refrigerating installation containing more than one thousand pounds of ammonia should be equipped with some means of safely drawing off all the ammonia in the system, in case of fire or other emergency.

This may be done by installing an emergency relief line from the low-pressure side of the apparatus. This line should be operated by a hand relief-valve and the ammonia passed by this valve should be conducted to a suitable mixer which will thoroughly mix the escaping gas with water and discharge it into the sewer or an outside body of water. This emergency pipe line should be equipped with a suitable check valve to prevent the water from working back into the refrigerating system.

The question of safety to the workmen is largely in the hands of the workmen themselves, just as it is in almost any industrial plant. For this reason it is important to have the work done by experienced and competent persons and under the direct supervision of one who is thoroughly versed in the operation and upkeep of refrigerating apparatus and who thoroughly understands the dangers that are associated with such machinery.

It is also important to have several of the employees learn approved methods of reviving persons who may be overcome by ammonia gas. The prompt application of artificial respiration, for example, may often-times be the only means of saving a life. In addition to giving prompt and efficient first-aid treatment, the services of a skilled physician should be secured as soon as possible.

General Care of Ammonia Compressors

The compressor should have a thorough inspection once each day when it is in operation. Examine the bearings to see that they are getting the proper amount of oil and that the ring or chain oiler is turning with the shaft. Notice if the oil is at proper height in crankcase; that there is no odor of ammonia in the compressor water jacket after standing overnight and that there is no knock or pounding in the cylinder. The machine should, in addition to the regular daily inspection, be gone over at regular intervals of 30 minutes for the first two hours after starting, and all bearings accessible to the touch should be felt to see that they are not heating. Also, carefully watch the pressures, temperatures, water supply and power. For the rest of the day an inspection should be made each hour.

When the crank bearings wear to such an extent that it is necessary to take up lost motion, first close the suction valve on the compressor and let the machine run until all the ammonia is out of the crankcase, then draw out the oil and remove the bearing bolts. Do not lose the shims which separate the boxes and keep them from binding against the crankshaft. Remove one thin shim from each bolt, so as to bring the boxes about one-thousandth of an inch closer together. If one is too much add shims made from thin paper, then draw the bolts firm and insert the cotter pin.

Occasionally, a compressor valve will stick owing to oil gumming on the valve, or to rust caused by moisture getting into compressors while pumping air pressure. In such cases it will be necessary to remove the valves, clean them, oil with ammonia oil, see that they do not stick or bind and put them back in compressor. Be careful that locknuts, capscrews and bolts are securely tightened and that the suction valve works freely after it is fastened into place.

Insufficient Ammonia Charge

An insufficient charge will be indicated by a sputtering sound in the expansion valves, and the frost line on the expansion valves will disappear; and if the valves are opened too much in an attempt to get the frost back to the machine, the valves, liquid header and the liquid line for some distance back will become frosted. This is because the expansion valves are opened so wide that the liquid line is unable to furnish the supply. The head pressure and back pressure will come down, the frost will disappear from the suction side of the machine, and the latter will run hot. Oil, poor ammonia and frosted coils will all have the same effect. The back and head pressure will drop, and the expansion valves will have to be closed more to accommodate the slower rate of evaporation.

Excessive head pressure is another frequent trouble. This is caused by air or foul gas in the system, condenser badly scaled on the water surface, oil in the condenser or some of the condenser coils blocked. In a double-pipe condenser the water pipes are readily scaled

if the water is not of the best; the annular space between the pipes is small, and this sometimes blocks with oil, scale and other foreign matter. Generally, if this happens, a number of the stands will be cold, and by going along the condenser and feeling them the "dead" ones can be located. These should be shut off with the water running on them and left standing for a few hours and then purged. This will decrease the head pressure. If the condenser is too small or the water warm or insufficient, high head pressure will be practically impossible to avoid.

There must be enough ammonia in the system to insure a solid stream of liquid going through the expansion valve, and there should be enough vapor evaporated from the liquid to make the evaporating coils take up heat equal to the capacity of the plant. In addition there must be enough surplus to allow for loss by leakage and for possible pocketing of the liquid.

Effect of Low Suction Pressure on Economy

In order to obtain low temperatures, a low suction pressure must be carried, but unless low temperatures are imperative it is uneconomical to have the suction pressure too low. The reason for this is that the volume of the gas at, say, zero pressure, is more than double that which it will occupy at twenty pound pressure, thus the compressor must handle more than twice the volume of gas and the volumetric efficiency is much lower. Also, the temperature of the refrigerator being low, the liquid ammonia must be reduced to the refrigerator temperature before doing useful work, which may amount to quite a large percentage of the work done.

Non-Condensible Gases in Refrigeration System

Non-condensible gases in a refrigerating system are always objectionable as they greatly reduce the efficiency of the machine. Furthermore, some gases are dangerous in that they may cause fire or explosions.

Air is the most abundant and troublesome gas found in the system. If it be a new system being put in operation, the custom is to pump out, creating as high a vacuum as possible in order to extract all air, but as we know it is not possible to create a perfect vacuum with a pump—there is bound to be some air in the system from the very first. Also if a pressure lower than atmospheric pressure is carried on any part of the system, air will leak in through leaky joints or rod packing.

Other non-condensible gases frequently encountered are due to the disintegration of the ammonia itself. Ammonia is a compound ($NH3$) composed of one part nitrogen and three parts hydrogen. Especially if high temperatures are allowed, some of the atoms of ammonia may disintegrate liberating hydrogen and nitrogen gas. Hydrogen is a very inflammable gas.

The presence of non-condensible gases can be detected by unusual high pressures. To ascertain if abnormal pressure is existent, measure the temperature of the cooling water at the outlet from the condenser. Then add from 5 to 10 degrees to this; it will closely approximate the temperature of the ammonia in the condenser. Now, note the pressure and compare the actual pressure with the theoretical pressure as indicated in the am-

monia tables. If the actual is in excess of the theoretical it will denote the presence of non-condensible gas. If ample cooling surface and a generous supply of cold cooling water is supplied there is not much likelihood of disintegrating trouble existing. Oil vapours and other gases may collect in small quantities. As already mentioned hydrogen is very inflammable while ammonia gas when mixed with air at high temperature will burn. If fire should occur within the system, an explosion could occur with disastrous results.

Purging

The frequency of purging a system will depend on the type and size of the plant, and may be once a week in some plants to once a month in others. It should not be done needlessly as there is always a loss of gas during the operation. The head pressure should govern the necessity of purging.

The usual and probably one of the best methods of removing the non-condensible gases from the refrigerating system is to pump the complete supply of ammonia into the condenser and then shut the compressor down and keep the cooling water in circulation for several hours until the gases have had time to separate, and the ammonia is of the same temperature as the cooling water. This being done the purge valve situated at the top of the condenser is opened slightly, until the fumes of ammonia become fairly strong or show a white fog, and then close. It is considered good practice to allow the system to stand for a period of time with the cooling water still running after the first purging, and then open the purge valve again.

Some engineers prefer to attach a hose to the purge pipe, the end of which is inserted in a pail or barrel of water. When the purge valve is first opened, large bubbles of air will be seen to rise through the water, but when the bubbles become small and a crackling sound is heard it means that ammonia is escaping and the valve should be closed.

Testing for Ammonia Leaks

Due to pitting or other causes, there may at times be a leak of the gas to the cooling water of a condenser, which may go on for an indefinite period undetected. It is well to test for such a leak, and it can be done by holding a piece of red litmus paper in the water as it leaves the condenser. If ammonia is present it will turn the litmus paper blue.

To test leaks in joints, soap is sometimes used. If the joint is painted with soap suds the ammonia gas will blow bubbles. Another and more satisfactory method is to burn a sulphur stick, and hold it close to a suspected leak. If dense fumes are formed it is a sure sign that ammonia is leaking.

To make sulphur stick, melt ordinary sulphur in a ladle, being careful it does not catch fire. Then take a small sized piece of wood six or eight inches long, and keep dipping the wood into the sulphur until quite a heavy coating of sulphur has formed on the wood.

Compressor Valves

A compressor, like any other reciprocating pump, is of necessity always equipped with two sets of valves, namely: suction and discharge.

The suction valves in vertical single acting machines are placed in the upper end of the piston.

They are made of drop-forged steel and are of ample proportion to insure easy access of the gas. The valve spring is of just sufficient strength to balance the weight of the valve on its seat, to insure quick opening of the valve at the beginning of the suction stroke.

A cushion chamber provided at the end of the stem relieves it from the shock of sudden opening at high speeds.

The discharge valves are placed in the safety head and are designed to give rapid opening and closing. They are also provided with a cushion to secure quiet operation.

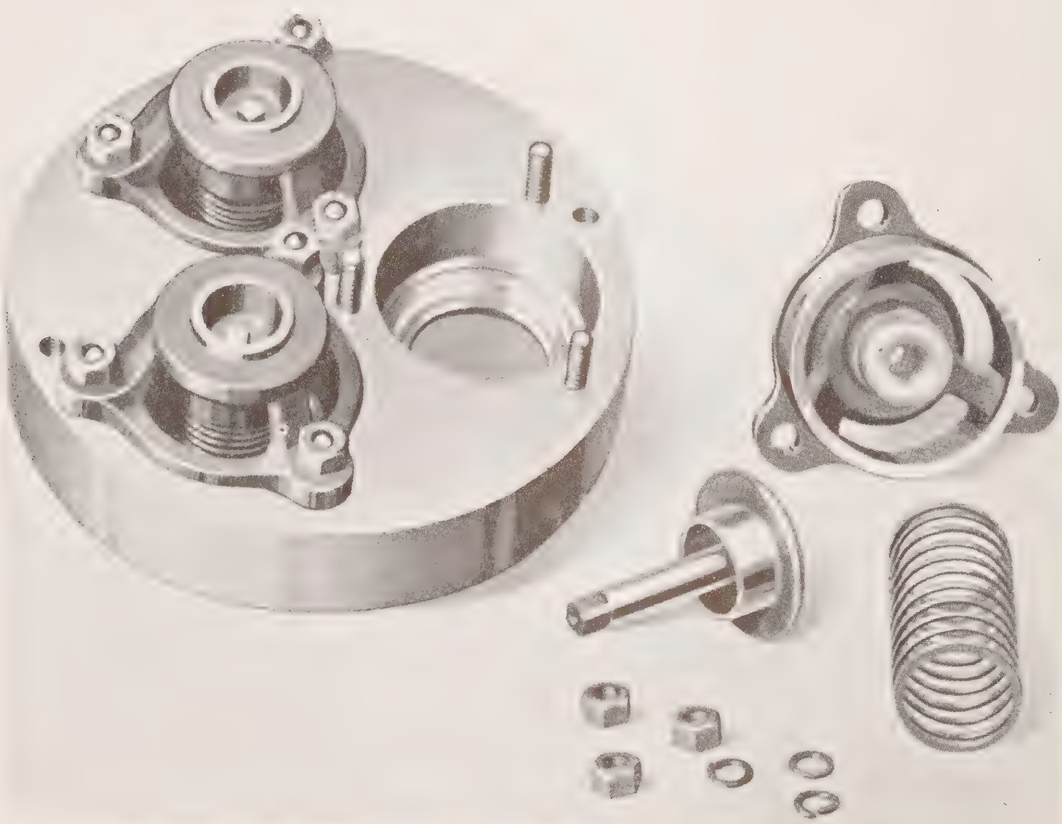


Fig. 4. Section of ammonia compressor cylinder assembly of the non-jacket type.
(Note the clearance pocket heads and the main and auxiliary stuffing boxes)

In double acting horizontal compressors, the valves are built into the cylinder case as shown in Fig. 5. Being double action, there are sets of both suction and discharge valves at each end of the cylinder. These valves may be of the poppet valve type or of the feather type.

Feather Valves

Instead of the poppet valve, the ring plate or feather valve is now commonly used, particularly on high speed machines.

The ring plates are made of special steel, are thin and light and are ground to a smooth surface. They are held in place by means of a light spring.

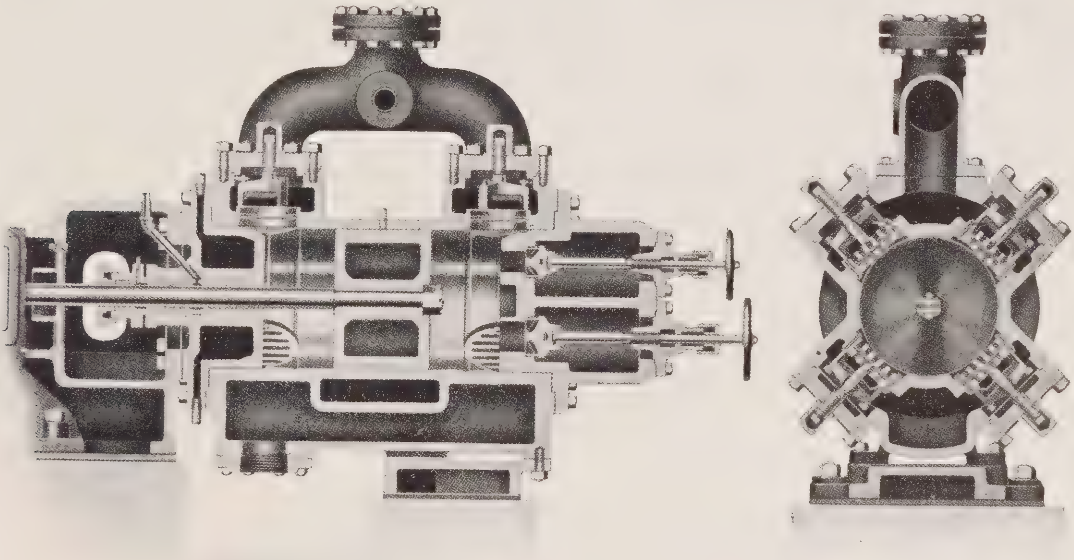


Fig. 5. Ammonia compressor discharge valves of the disc type.

The valve itself consists of light strips, restrained but not rigidly secured at the ends and free to lift from the seat in the middle, to permit the passage of gas. Each element of the valve consists only of a light, thin rectangular metal strip, covering, when seated, a somewhat smaller slot. The valve seats on a flat ground surface. The feather valve requires no springs.

Some of the advantages claimed for this type of valve are that it is light, creates no sudden impact and knock, closes and opens quickly, thus reducing leakage, has a large valve opening without much lift, is easily accessible and can be quickly replaced. They require, however, somewhat more clearance space.

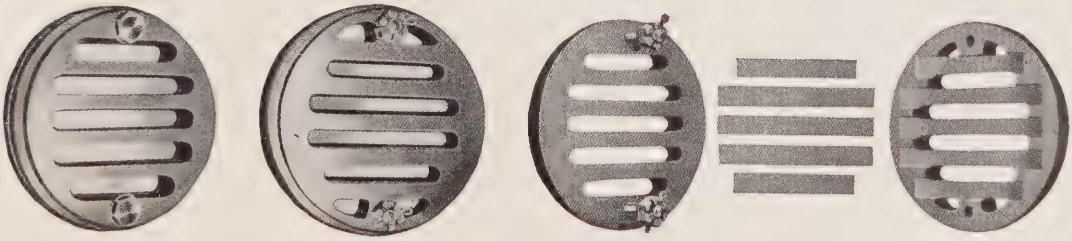


Fig. 6. Ammonia compressor valves of the feather type.

Safety or "False" Head

In compressors, any clearance space between the cylinder head and the piston when at end of stroke is detrimental, as the volume of gas contained in this space after compression is not discharged from the cylinder, thus decreasing the volumetric efficiency of the machine.

Nevertheless, a certain amount of clearance space must be allowed for two reasons: firstly, the piston must not hit the cylinder head and adjustment cannot be made so fine that all the clearance space is taken up and still not allow the piston to hit, and secondly, allowance must be made for any liquid which is incompressible, or any metal such as a broken part of a piston ring which might accidentally get between the piston and cylinder head.

In vertical single acting compressors the clearance space can be cut down to a minimum by using what is called a safety head. It consists of a loose or false head beneath the cylinder head, fitted to a ground seat and held in place with heavy springs. The clearance space between the false head and the piston at the end of its stroke is adjusted so as to be almost nil. Should liquid or foreign substance get in the clearance space, the springs will allow the head to rise and thus protect the compressor from damage.

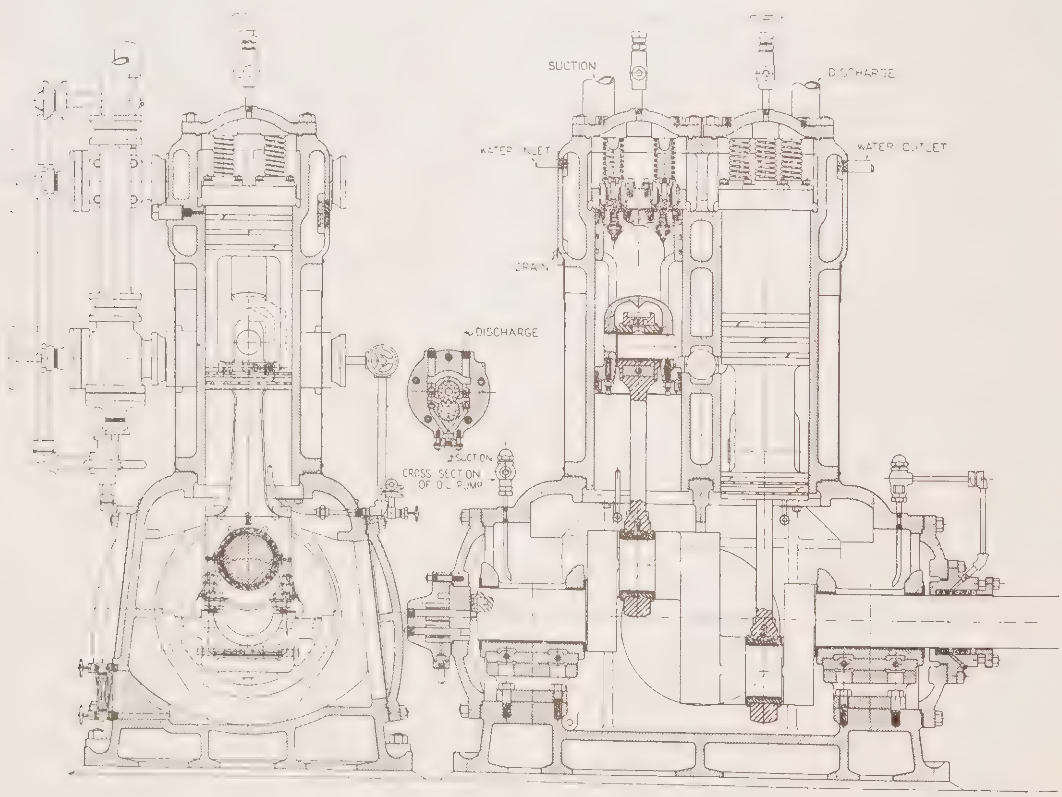


Fig. 7. Sectional assembly of vertical refrigerating compressor.
(Note position of the false cylinder head)

The compressor discharge valves are placed in the safety head, reducing the clearance space of the ports to a minimum.

One objection to the use of the false head is that the compressor must have more head room.

The Wet Compression System

In an ammonia refrigerating compressor the most common pressures used are about 15 pounds in the suction and about 160 pounds in the discharge.

Compressing the gas from the suction pressure to the discharge pressure has the effect of causing the cylinder to become very hot, owing to the mechanical energy driving the compressor all being converted into heat energy.

In the dry compression system, a water jacket surrounds the cylinder whereby the circulating water through the jacket carries off a certain percentage of the heat and prevents the metal becoming excessively hot.

With the wet compression system, the elimination of the excessive heating is accomplished by allowing the suction gas to return to the compressor in a slightly saturated condition, that is, there still remains in the gas a certain amount of moisture. These liquid particles evaporating, cool the gas so that it reaches only a moderate temperature. With this system, no excessive temperature is experienced and no water cooling jackets are required.

In the operation of the wet compression system, an effort is made to inject just sufficient liquid with the suction gas, that when full compression has taken place a small amount of superheat exists in the compressed gas. The superheat insures that no liquid remains in the gas at the end of compression.

Some of the advantages claimed for the wet system over the dry system are:

(1) No exterior cooling of compressor cylinders required.

(2) The wet system may be worked with a higher back pressure, thereby allowing a higher density of the gas in the refrigerator coils, and therefore, the surface of refrigerating coils may be reduced.

(3) The hot gases in the dry system become heated and expanded, preventing the compressor from drawing in a full charge of gas.

(4) the cool temperature of the cylinder in the wet system, prevents the oil taken into the compressor through the stuffing boxes, from vapourizing and being carried into the pipes and condenser, where it would condense on the surface, thereby spoiling their cooling effect.

(5) Ammonia in a liquid state is a very good lubricator, therefore very little oil need be injected into the cylinder when using the wet system.

Although the advocates of each system claim advantages for the particular one they prefer, experience does not seem to show much to choose between the two systems from an economical standpoint.

The Double Acting Compressor

The double acting compressor derives its name from the fact that it compresses gas at both ends of the cylinder. This has the advantage that it requires less machinery and is therefore lighter and subject to less wear than the single acting compressor, in proportion to the work done.

It has another advantage in that it may be operated as two separate machines, provided each end has its own suction and discharge line, or, by a system of piping and valves, it can be made to perform either as a two single-acting or as a one double-acting compressor.

This arrangement may be useful if a condition arose in which two rooms in a storage plant had to be kept at different temperatures.

The Stuffing Box

A disadvantage of the double-acting compressor as compared with the single-acting, is that the piston rod gland must be packed tight enough to resist the escape of the high pressure gas without creating excessive friction or without scoring the rod or burning the packing.

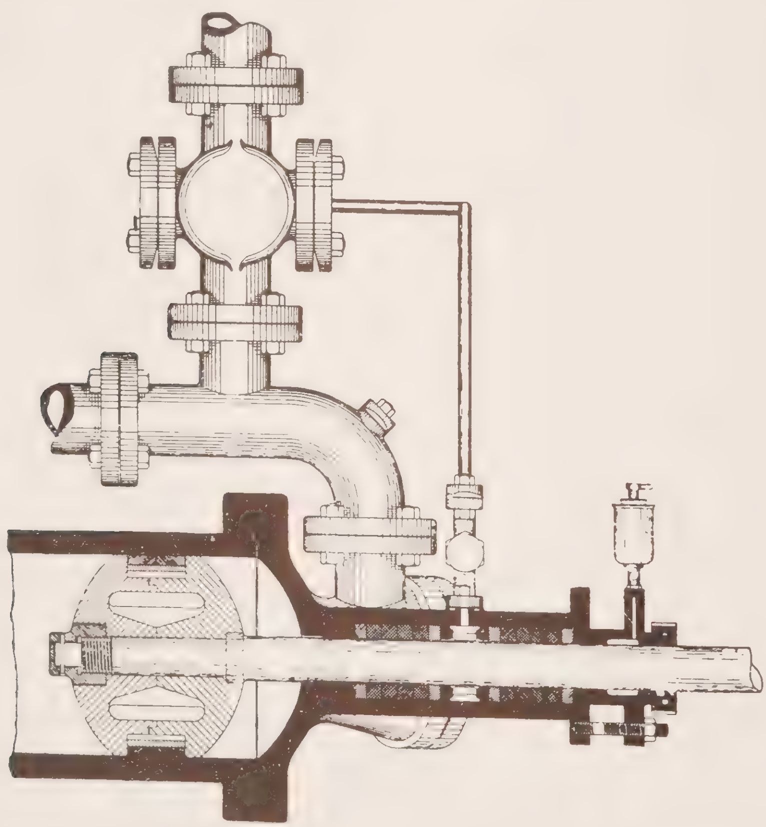


Fig. 8. A type of stuffing box used in connection with refrigerating compressors.
(Note method used of returning any leakage past the inner packing to the suction side)

A common type of packing gland is shown in Figs. 8 and 9. There is a loose ring or oil lantern, which, placed in the centre, divides the packing of the box into an inner and outer packing. The open space thus made by the iron ring is connected by means of a pipe with the suction side of the compressor. It can therefore be seen that any ammonia which is forced through the inner packing during compression period will not be lost, but be drawn back into the suction side.

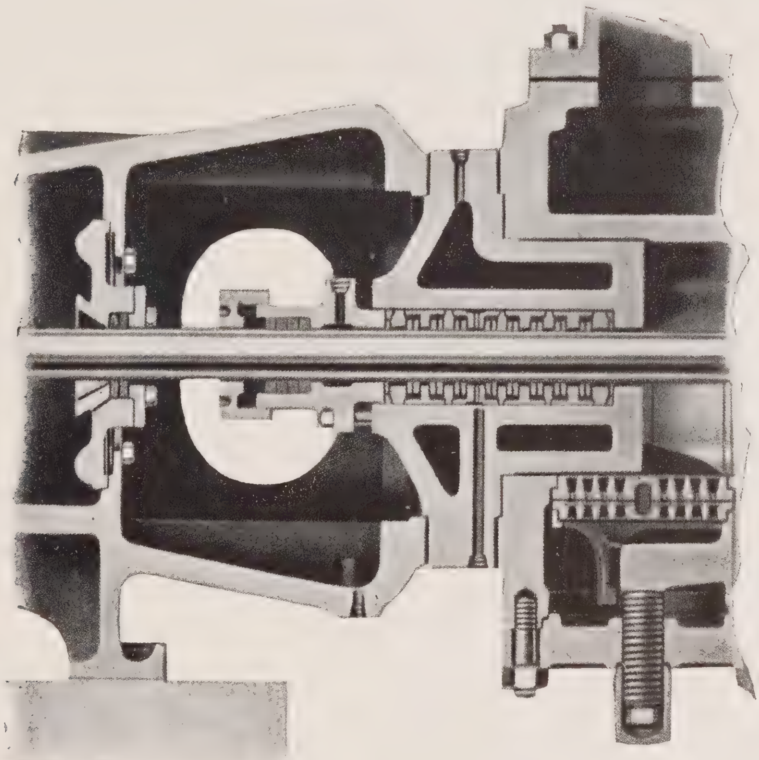


Fig. 9. Sectional view of stuffing box of ammonia compressor.

As the outer packing is kept only under suction pressure it is not very difficult to keep tight. To prevent, however, as far as possible any ammonia escaping through it, the front gland is made hollow and kept full of special oil by means of a sight feed lubricator or oil pump. This oil not only absorbs the ammonia gas but also lubricates the piston rod and keeps it in good condition, so that with ordinary care and by keeping the packing gland in good condition, no ammonia gas can escape.

To the operator, the shaft packing is probably the most troublesome and requires more care than any other part of the machine, because any leakage is a source of loss much greater than in the case of the steam engine. Owing to the varied and rapid changes in temperature, a gland may be tight at one time and leaking at another, or, it may be just

right at one time and far too tight at another time when it will cause excessive friction, thus increasing the power required to drive the machine and creating a heat that may burn the packing or score the shaft.

Packings are made of many designs and materials: some engineers prefer one kind while others may get good results with some other kinds. The different packings used vary from soft or fibrous packing to different types of metallic packing.

In packing a gland, care must always be taken that the gland is drawn up evenly, but not so tight that it will cause scoring of the shaft. Care should be taken that the oil lantern is in its proper place, otherwise the oil port may be closed off. The gland pressure must be adjusted while machine is in operation, owing to the varying changes in temperature of the cylinder.

No great difficulty is experienced with the packing of glands in single acting compressors, for in this case it must only be tight to suction pressures, which are comparatively low.

Compound Refrigerating Compressors

Where low temperatures are required in storage rooms, necessitating low boiling point of the ammonia in the evaporating coils which can only be maintained by means of evaporating at low pressure and a resultant highly expanded gas:

Under these circumstances it may be found advisable to use compound compressors with a low pressure cylinder and valve of copious dimensions.

The compound or two stage compressors are relatively of smaller dimensions and require less power than the single stage, but are much more complicated.

The cycle of events in a two stage compressor is as follows:

Ammonia gas is drawn from the brine cooler or evaporator to the suction side of the low pressure cylinder and compressed in this cylinder to a pressure somewhere in the neighbourhood of sixty pounds. It then discharges into an intermediate gas cooler. This cooler consists of an enclosed tank containing a coil of piping. The gas surrounds the piping while water circulates through it. From this cooler the gas proceeds to an intermediate receiver in which it mixes with the liquid ammonia which is piped back from the condenser.

The evaporation of a portion of the liquid ammonia cools the gases which are then drawn to the suction of the high pressure cylinder and being compressed still further in the cylinder, are discharged into the condenser and through the cooling by water in the condenser are converted to a liquid. This liquid, as previously mentioned, then flows to the intermediate receiver from whence it flows through piping to the brine tank or evaporator, the flow being regulated by an expansion valve.

By-pass piping is installed whereby the liquid may by-pass the intermediate receiver and feed direct to the evaporator. If operated under these conditions the cycle of the ammonia would be: from the evaporator to the low pressure cylinder, to the intermediate

cooler, to the high pressure cylinder, to the condenser, to the evaporator from whence it started.

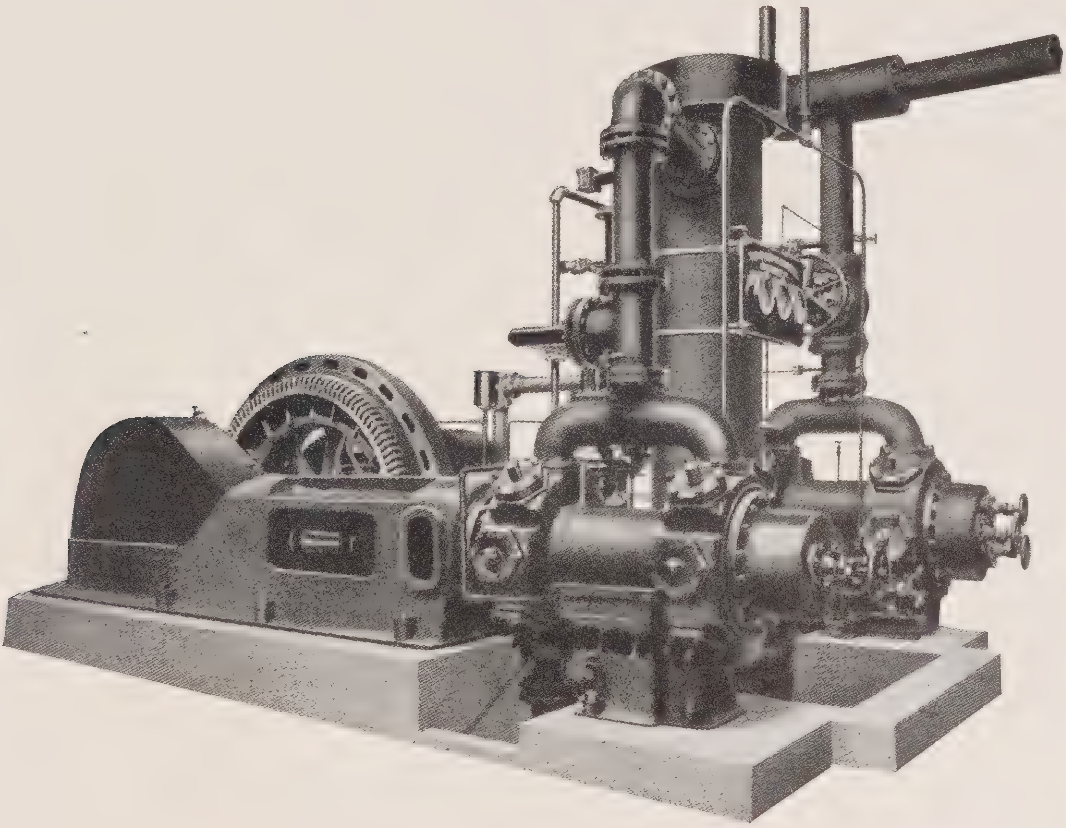


Fig. 10. Two-stage feather valve ammonia compressor with synchronous motor drive.

Why Clearance Pockets in Ammonia Compressors (Power)

The advent of motor and oil-engine drives for ammonia compressors has compelled the use of clearance pockets in the compressor. But just why such pockets change the load on the engine or motor can be illustrated by indicator diagrams.

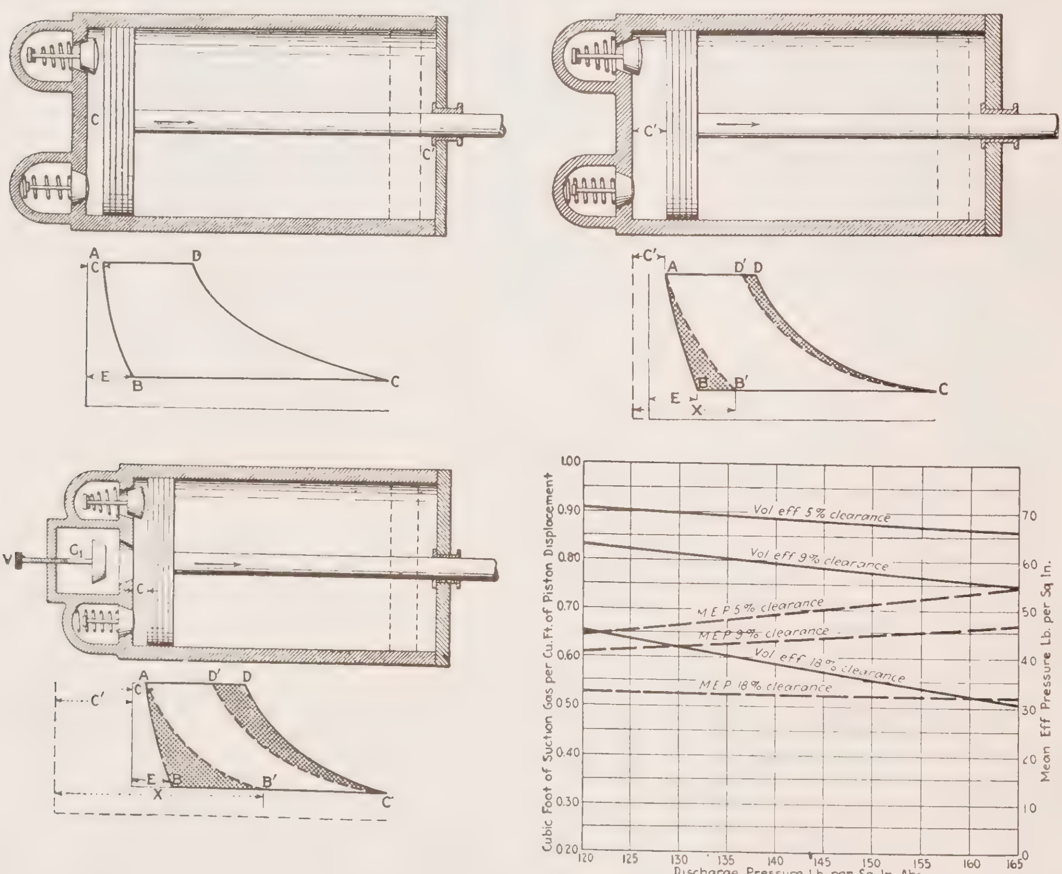
The compressor's function is to withdraw the ammonia vapor from cooling coils, as fast as the liquid boils, in order that the pressure and the temperature remain constant. If the amount of heat to be removed from the cooler, ice tank, etc., be less than normal, the ammonia will not evaporate so rapidly and the weight of vapor passing out the coils will be less than usual. If the compressor operates at a constant speed, it draws in more cubic feet of gas than the coils will produce without a drop in pressure. The coil pressure drops as does also its temperature, and this continues until the new temperature difference between the ammonia and the material being refrigerated is such that the heat flow is great enough to

evaporate the ammonia sufficiently to maintain the vapor pressure. But this stability is soon disturbed, inasmuch as the cold-storage temperature drops with the increased heat flow. The ammonia temperature and pressure again drop until equilibrium is established.

Increased Power With Low Pressures

Even though the resulting low temperatures were not objectionable, the increased amount of power required per ton of refrigeration makes the system expensive, for the power needed to remove and compress a pound of ammonia vapor increases with a decrease in the suction pressure, the condenser pressure remaining the same.

As long as steam engines were used for compressor drive, the speed of the compressor could be varied to meet changes in the evaporating coil duty, and it was easy to hold a constant coil pressure. The horse power required per ton of refrigerating duty did not show a wide variation no matter what the load was.



FIGS. 11, 12, 13 and 14. Sectional view of cylinder of compressor showing principle of clearance pockets and chart.

With the adoption of the electric motor and the oil engine, as the compressor prime movers, the problem took on a different aspect. While the oil engine is capable of operating at variable speeds, constant speed is desirable, and with alternating-current motors constant speed only is possible. If the compressor capacity is to vary with the boiling rate of the evaporating coils or apparatus, other means than a variation in compressor speed must be adopted. Necessity being the mother of invention, the clearance-pocket compressor came into being.

Use of Clearance Pockets

How the clearance pocket affects the horse power requirement of the compressor is not difficult to understand.

In Fig. 11 we have a double-acting compressor provided with the clearance "C" at the head end. If the piston moves toward the right, the vapor at the discharge pressure of, say, 135 lb. gauge, or 150 lb. absolute, trapped in the clearance "C", will expand, and when it reaches the suction pressure of, say 30 lb. abs., or 15 lbs. gauge, will fill the cylinder volume represented by "E", the change in pressure and volume during the interval being represented by the line AB. During the remainder of the stroke a volume of vapor proportional to BC is drawn into the cylinder from the evaporating coils. At "C" the piston reverses and on its return stroke compresses the vapor in the cylinder, the pressure-volume changes of the cylinder charge of gas being represented by the line CD. At D the cylinder pressure is equal to the pressure in the discharge pipe and the discharge valve opens, permitting the gas to be forced out during the remainder of the stroke as represented by DA. The figure ABCD is the indicator diagram of the compressor, and the area of this divided by the length is proportional by some scale to the average pressure in the cylinder which the driving power must overcome.

Effect of Increased Clearance

Suppose now the cylinder be extended so that the clearance is doubled, as in Fig. 12, the volume of gas in the clearance space is now twice that shown in Fig. 11, and when this expands down to the suction pressure at B′ it fills a volume X twice the volume E of Fig. 11. The B′ C volume of gas drawn into the cylinder from the evaporating apparatus is less than BC. The compression line CD′ runs less steep than CD and the indicator diagram becomes AB′ CD′. It will be seen that the work areas ABB′ and DCD′ have been eliminated and the net power needed per stroke has been reduced, as has also the net volume of vapor withdrawn from the evaporator. It is then possible to regulate the cubic feet of vapor handled by altering the clearance of the compressor and at the same time reduce the horse power per stroke, but the horse power per ton of refrigeration is increased.

Pockets Decrease Capacity

As an example of a clearance pocket consider Fig. 13, when a cavity has been placed in the cylinder head so that it can be placed in communication with the cylinder by opening the valve V. With the valve closed, the indicator diagram would be similar to ABCD, but if V is opened, the increased volume of vapor in the clearance pocket equal to 18 per cent

of the cylinder volume causes the diagram to take the form AB′ CD′. The decrease in the volume of vapor drawn into the cylinder, B′ C against BC, is apparent and the two cross-hatched areas are proportional to the decrease in horse power used in the work of compression.

While the relative volumes of such pockets vary, it is customary to have two or three in each machine. For example, in a single-stage machine with a 5 per cent normal clearance, opening one pocket makes the total clearance 9 per cent, while this is increased to 18 per cent by opening a second pocket. The influence of the additional clearance can be observed by an examination of Fig. 44, which shows the variation in mean effective pressure and cubic feet of suction gas handled per cubic foot of piston displacement; this chart is for 30 lb. abs. suction pressure, but the same general shape is found in the curves for other suction pressures.

Safety Valves

Should the condenser cooling water fail, or should some valve inadvertently become closed, there is always present the possible danger of an excessive pressure building up in the high side of the system, sufficient to cause an explosion.

There are several precautionary appliances in use to guard against this emergency. One method is to equip the machine with an automatic device which when excessive pressure is present in the condenser, turns the electric switch to the motor driving the compressor and shuts the plant down.

Another common practice is to install a safety or relief valve on the discharge line from the compressor, the outlet of which is connected to the suction line of the compressor and which when functioning by-passes the gas direct to suction line instead of to the condenser.

The Province of Ontario, at the present time, does not appear to have a definite regulation regarding this matter, but the Provinces of Alberta and Manitoba regulations are as follows:

(1) Every refrigerating machine shall be equipped with at least one approved automatic by-pass valve connected between the pressure imposing element and the main discharge valve. The discharge outlet of each valve shall be connected to the suction side of the main suction valve.

(2) Automatic by-pass valves shall be set and sealed to open at the following pressures respectively for refrigerating machines employing:

- (a) Ammonia—set valve at not over 250 lbs. per square inch.
- (b) Carbon Dioxide—set valve to open at not over 1,500 lbs. per square inch.
- (c) Ethyl Chloride—set valve to open at not over 50 lbs. per square inch.
- (d) Methyl Chloride—set valve to open at not more than 150 lbs. per square inch.
- (e) Sulphur Dioxide—set valve to open at not over 120 lbs. per square inch.

(3) Automatic by-pass valves should be of the same size as safety valves and the size of valves to be used in the refrigerating systems respectively shall be as follows:

For the system of 3 to 25 tons capacity—use one ½ inch valve
For the system of 26 to 60 tons capacity—use one ¾ inch valve
For the system of 61 to 100 tons capacity—use one 1 inch valve
For the system of 101 to 175 tons capacity—use one 1¼ inch valve
For the system of 176 to 250 tons capacity—use one 1½ inch valve
For the system of 251 to 450 tons capacity—use one 2 inch valve
For the system of 451 to 900 tons capacity—use two 2 inch valves

In addition to the above section of the regulation, there is also a section which reads in part as follows:

(1) Every liquid receiver, shell type condenser and shell type evaporator which is capable of being isolated, shall be equipped with a ½ inch approved automatic safety valve discharging to the atmosphere.

(2) Such safety valve shall be set and sealed by the inspector to open at a pressure not higher than the maximum allowable working pressure of the receiver, shell type condenser or shell type evaporator to which it is attached, and in any case at a pressure not higher than the following for machines employing:

(a) Ammonia—set valves to open at not more than 350 lbs. pressure.
(b) Carbon Dioxide—set valves to open at not more than 2,000 lbs. pressure.
(c) Ethyl Chloride—set valves to open at not more than 100 lbs. pressure.
(d) Methyl Chloride—set valve to open at not more than 175 lbs. per square inch.
(e) Sulphur Dioxide—set valves to open at not more than 150 lbs. pressure.

(3) Safety valves and automatic by-pass valves on refrigerating machines using refrigerants other than those hereinbefore mentioned shall be set to open at pressures determined by the Chief Inspector.

(4) Safety valves, pressure relief and pressure limiting devices shall be made of material suitable for the refrigerant employed and, where practicable, their working parts shall be non-corrodible and shall be set, marked and sealed by the manufacturer.

Discharge of Refrigerants

(1) The ammonia, carbon dioxide, ethyl chloride, or sulphur dioxide passed by the automatic safety valves shall be discharged to the atmosphere but ammonia may be discharged into a suitable body of water.

(2) Where an irritant or inflammable refrigerant is used, the discharge of the refrigerant from the safety valve, if to the atmosphere, shall be conducted to the outside not less than twelve (12) feet above the grade, and not closer than ten (10) feet to any opening in any building, or closer than twenty (20) feet to any fire escape. The discharging pipe shall be not less than the size of the relief valve outlet. The discharge from more than one relief valve may be run into a common header, the area of which shall be equal to the areas of the pipes connected thereto, and the outlet of which shall be turned downward.

(3) The gases passed by the automatic safety valves may be discharged into a ventilating stack, the inside diameter of which is at least twelve times the diameter of the gas-discharge outlet, the first possible outlet of the stack above the discharge end of the gas-discharge pipe being at least ten feet above the roof. When such stack is used for this purpose the discharge end of the gas-discharge pipe shall be turned upwards.

Ammonia Discharged into Water Tank

(1) When ammonia is discharged into a tank of water, the tank shall not be used for any other purpose. At least one gallon of fresh water for every pound of ammonia contained in the receiver shall be automatically maintained in the tank. Provision shall be made to prevent the water from freezing, without the use of salt or other chemicals.

(2) The tank shall be substantially constructed and if of open type shall be provided with a hinged cover. If a tank of enclosed type is used, it shall have both a water inlet and a vent hole at the top. No horizontal dimensions of the tank shall be greater than one-half the height. The discharge pipe from the pressure relief devices shall discharge the refrigerant at the centre of the bottom of the tank and the portion of the discharge pipe within the tank shall be of lead, with a one-sixteenth inch vent hole above the water level. There shall be no opening in the tank below the water level, which shall be at least six inches below the top of the tank.

Safety valves on boilers should they leak a small amount, is of little importance from an economical standpoint but with a refrigerant gas, a leak to the atmosphere is an important matter, as gas costs money.

Figs. 15 and 16 show two types of atmospheric safety valves used on refrigerating systems.

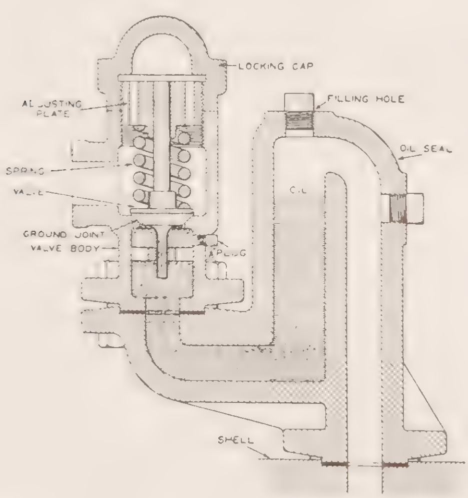


Fig. 15. Safety valve used with refrigerating systems.
(*Note oil seal under disc*)

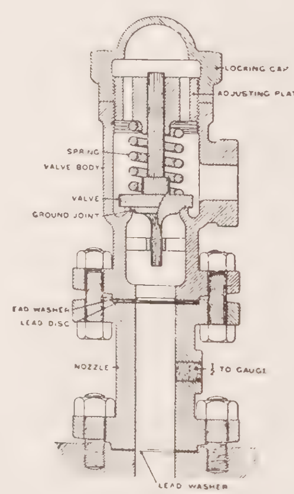


Fig. 16. Another type of safety valve used with refrigerating systems.
(*Note lead disc placed between nozzle and body of valve*)

The safety valve (Fig. 15) consists of two separate parts, namely, the lower section, known as the oil seal, and the upper section or body, which is a ground seat pop safety valve. The spring on this valve is set by means of an adjusting plate. As it is not safe to trust to a ground joint in the case of ammonia, the oil seal is provided so that the ammonia pressure comes on the surface of the oil and the ground seat merely has to hold this liquid. In case of the valve being lifted and the oil blown out, it is simply necessary to take the pressure off the condenser, remove the 1/8 inch plug from the safety valve body just below the seat of the valve and the filling plug on the top of the oil seal.

Fill the reservoir with a rather heavy ammonia oil until it appears at the 1/8 inch opening; then after replacing the plugs the valve is ready for service. In filling the reservoir with oil it is important that it be filled through a fairly long tube to insure that the oil will run in the reservoir and not into the body of the condenser.

Fig. 16 consists of two separate parts, namely, the lower section, known as the nozzle, and the upper section or body, which is a ground seat pop safety valve similar in all respects to that used in the oil seal type. To avoid trusting to a ground joint, a rupturing lead disc or diaphragm is placed between the nozzle and the body of the valve. Above the disc a lead washer is set in, so that the lead disc will not be cut by the edge of the iron valve body. This disc will rupture at about 40 lbs. less pressure than that for which the safety valve is set. In case the disc ruptures, it is necessary to remove the pressure from the condenser in order to replace it with a new one.

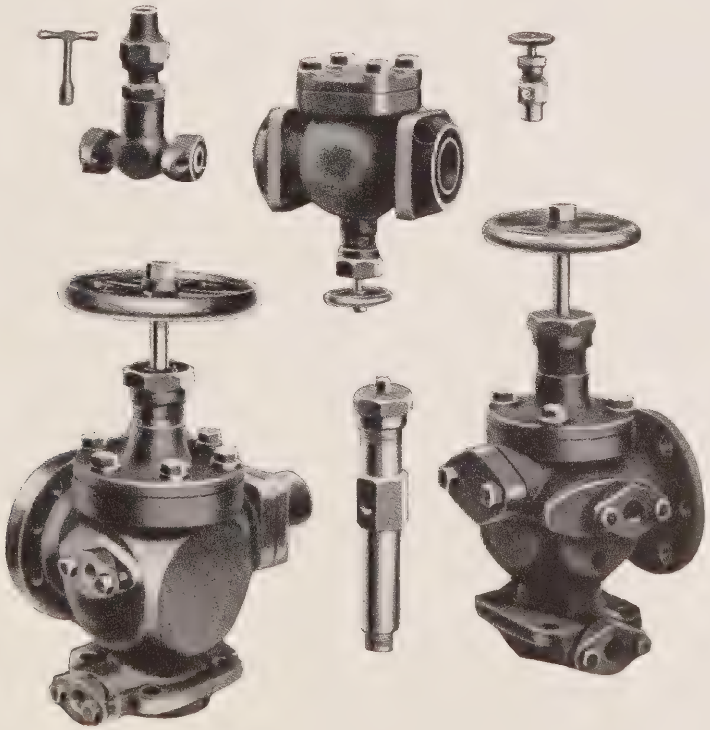


Fig. 17. Different types of valves used with refrigerating systems.

These valves must never be allowed to exhaust into the building, but should always be piped to the outside to a safe place of sufficient height that no person in the vicinity may be affected by the fumes.

Oil Separators

Oil in the ammonia system should not be allowed, as it forms a coating over the shell and tubes and as it is a very poor conductor of heat, it prevents the rapid transmission of heat through the wall and therefore lowers the efficiency of the system. To prevent oil from the compressor cylinders reaching the condenser there should always be an oil separator on the discharge line from the compressor. This trap should be drained out frequently from the bottom.

The oil trap acts on the same principle as a steam separator. It causes a sudden change in the direction of the flow of gas which causes the oil which is heavier to be thrown against the surface, and drain to the bottom of the separator. There are different designs of separators; some are built to give the gas a spiral direction.

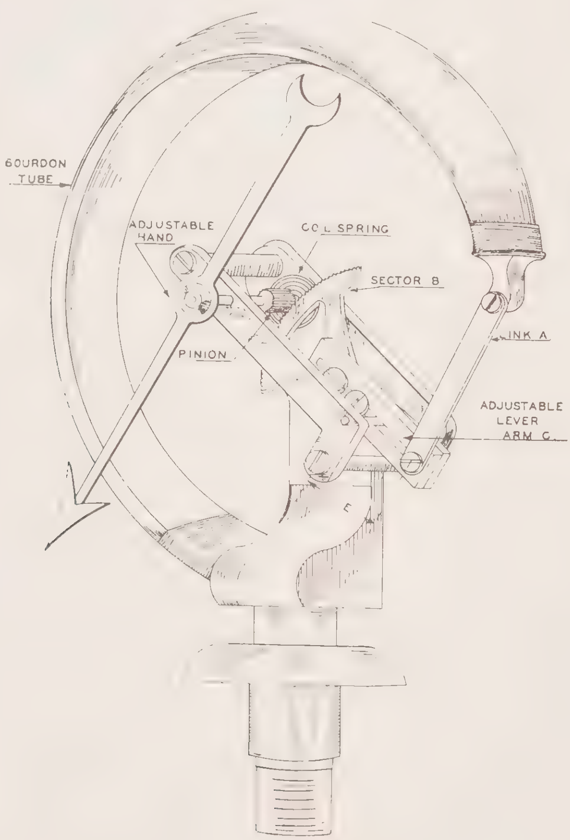


Fig. 18. Pressure gauge.
(*Note steel tube used with ammonia systems*)

Pressure Gauges

Although Ontario, at present, has no regulations respecting gauges on refrigerating systems, Alberta and Manitoba regulations state "every refrigerating equipment shall be provided with approved pressure gauges; one indicating pressure in the condenser or high pressure side and one for indicating pressure in the evaporating or low pressure side".

Like steam gauges, the gauges used on refrigerating systems should be tested regularly. Operators should always bear in mind that the tube in a gauge used with ammonia should always be made of steel, as this gas has a deteriorating effect on anything made of copper or brass.

Gauge Glasses

When a water gauge glass on a steam boiler breaks, practically the only loss is the glass and the time to renew it, but in a refrigerant system it is quite different, for gases cost money, and further, a leak of ammonia or of some other gases used as refrigerants is dangerous to life.

It is for this reason that it is wise to always equip with ball cocks, similar to that illustrated in Fig. 19, which automatically close, should the glass break. All parts of the gauge glass fitting must be made of steel and capable of withstanding high pressure.

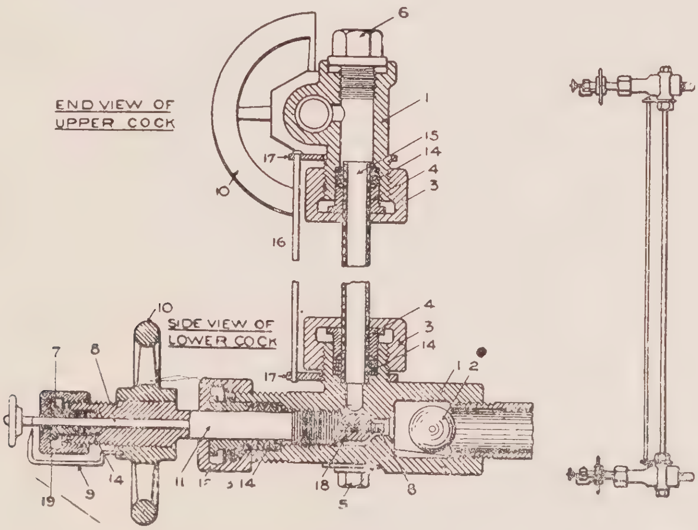


Fig. 19. Gauge glass fittings used with refrigerating systems.
(Note ball gauge cocks)

Other Gases Used for Refrigerating Purposes

We have so far spoken of ammonia as the only refrigerating agent, but although it is by far the most commonly used, there are a number of other gases also employed.

For instance on board ship and in hospitals, carbon dioxide is commonly used, the main reason being that unlike ammonia it has no smell. Also, it is not dangerous when

inhaled and it will not burn. It requires, however, a much higher pressure to liquefy than does ammonia.

There are three other gases in common use in small machines, namely, ethyl chloride, methyl chloride and sulphur dioxide. These gases do not require so high a pressure and so low a temperature to liquefy. In small domestic machines in which these gases are usually used, the cooling is done by a fan blowing air on the condenser instead of the water cooling apparatus necessary in ammonia and carbon dioxide machines.

Pressures and Temperatures at Which Refrigerating Gases Liquefy

A comparison of the pressures required to liquefy different gases when cooled in the condenser to a temperature of 86°, which is about the temperature that could be expected when cooled by water or air of ordinary summer temperature:

	Temperature	Pounds Gauge Pressure
Carbon dioxide	86°	1025
Ammonia	86°	155
Sulphur dioxide	86°	52
Methyl chloride	86°	83
Ethyl chloride	86°	12.5

At the temperature of 86° the heat of evaporization (latent heat) for the above mentioned gases are as follows:

Carbon dioxide	(CO_2)	=	27	B.T.U.
Ammonia	(NH_3)	=	491	"
Sulphur dioxide	(SO_2)	=	143	"
Methyl chloride	(CH_3Cl)	=	158	"
Ethyl chloride	(C_2H_5Cl)	=	162	"

Sulphur Dioxide Used as Refrigerant

In the field of large refrigeration plants, ammonia as a refrigerant, is the most commonly used, but in small plants, sulphur dioxide predominates.

Sulphur dioxide (SO_2) is a gas formed by the union of sulphur and oxygen, during process of combustion.

The latent heat of sulphur dioxide is about one-third of that of ammonia, therefore the compressor must compress about three times the volume of sulphur dioxide gas as it does of ammonia for the same amount of refrigeration. This, however, is not a particularly important matter in small compressors since for mechanical reasons they require to be of workable dimensions.

Sulphur dioxide condenses much more readily than does ammonia. For instance, at a temperature of 86 degrees, ammonia requires a pressure of 155 pounds to condense it, while at the same temperature, sulphur dioxide will condense at a pressure of 52 pounds.

It is an easy matter to condense sulphur dioxide by using a current of air blowing on the condenser coils, without having to resort to an excessive pressure.

For instance, it will condense at a temperature of 100 degrees when subjected to a pressure of 85 pounds.

Small domestic refrigerating sulphur dioxide systems usually have the condensers cooled by air from a fan driven by the motor that drives the compressor. This makes them less expensive and more portable.

Sulphur dioxide is non-explosive and non-inflammable and although extremely irritating when breathed and of a disagreeable odor, it is practically non-poisonous, unless present in very dense quantities. It is heavier than air and therefore has no great tendency to rise.

When the gas is mixed with water it forms a very weak acid, known as sulphurous acid (H_2SO_3). This acid has a slow corroding effect on metal and for this reason the operator should see that no water is allowed to enter the system.

In testing for leaks in a sulphur dioxide system, a small quantity of ammonia gas directed to the leak will cause dense whitish fumes.

Domestic Refrigerators

Differing only in size, the small domestic refrigeration compression system is identical with the large sytem.

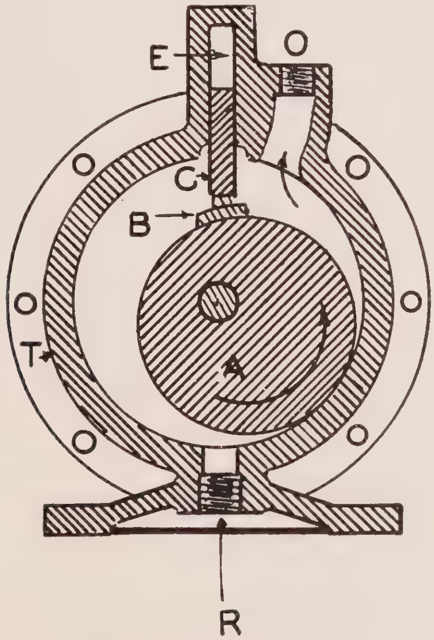


Fig. 20. Rotary pump used in some types of small sulphur dioxide refrigerating systems as a compressor.

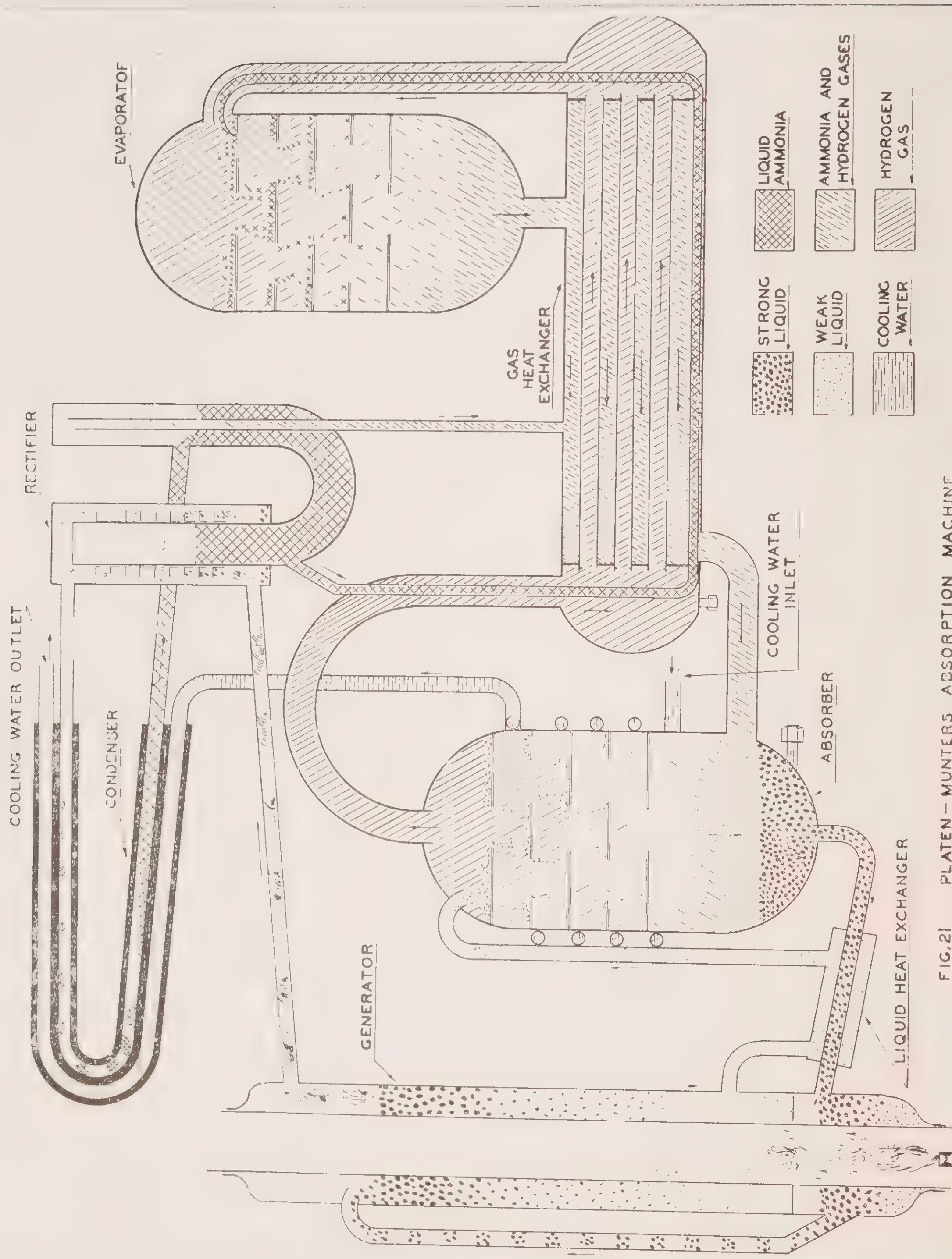


Fig. 21. Ammonia absorption refrigerating system.
(Note the absence of all valves and moving parts.)

The compressor is of the same design as that used in a large system in most cases, but some manufacturers prefer using the old time rotary pump (Fig. 20) in a somewhat modified form, instead of using the piston type.

Another type of domestic refrigerator uses the ammonia absorption system. The peculiar feature about this system is that there are no moving parts. The cycle of the refrigeration can be followed in Fig. 21.

The strong liquid (distilled water and ammonia only slightly stronger than household ammonia) is heated by the gas flame in the generator. The ammonia vaporizes and passes into the rectifier, where a constant temperature is maintained by the evaporation of ammonia from the previously liquefied ammonia in the bottom of the U-tube. The ammonia then passes from the rectifier through the water cooled condenser, where it is cooled and liquefied, the liquid ammonia flowing back into one leg of the rectifier. When the level of the ammonia in the rectifier U-tube becomes higher than the inlet pipe into the evaporator (located in the chilling compartment), the liquid ammonia flows from the rectifier through the heat exchanger into the evaporator, where it evaporates and absorbs heat from the box.

A hydrogen gas atmosphere in the evaporator causes the ammonia to evaporate, maintaining a constant pressure in the system and requiring no valves or checks of any sort. As the ammonia evaporates into the hydrogen, the mixture being heavier than the hydrogen itself, sinks to the bottom of the evaporator, passes through the gas heat exchanger and into the absorber.

In the absorber the ammonia and hydrogen meet a stream of weak liquid which has been cooled in its passage from the generator. The liquid readily absorbs practically all the ammonia in the gas mixture. Heat is given off when the ammonia dissolves in water, so the absorber must be cooled. The hydrogen being insoluble in water and being lighter than the incoming mixture of ammonia and hydrogen, rises and flows again to the evaporator, which is at a slightly higher level than the absorber. The mixture of water and ammonia sinks in the absorber and passes by gravity back to the lower section of the generator.

It is lifted from this point to the upper part by means of the thermo-syphon actuated by heat applied at this point. The heat supplied not only lifts the liquid from the lower level in the generator to the higher level in the generator, but also releases ammonia from the strong liquid to repeat its cycle.

TYPES OF CO_2 MACHINES FOR REFRIGERATING PLANTS

The wide application of carbon-dioxide refrigerating machines in hotels, office buildings, hospitals, and industrial plants, as well as on shipboard, increases the range of subjects with which the operating engineer must be familiar.

The fact that the discharge pressure of the system may be over 1,000 lb. per square inch, and the suction pressure around 300 lb., has caused many engineers to feel that unusual difficulties may be expected. This, however, is not a true picture, for if the piping is made of the proper thickness, there is no more danger of leaks than with ammonia, and with the correctly designed compressor the unit bearing pressures are low.

The carbon-dioxide system, like the ammonia, is made up of an evaporator, a compressor and a condenser, each having minor accessories. It is the practice to place the evaporating coils and the condenser as close to the compressor as possible, to reduce the number of points that might give trouble under unusual conditions.

The action in the CO_2 system is as follows: Liquid is admitted into the evaporating or refrigerating coils by an "expansion," or control, valve. Here it evaporates at, say 300 lb., and the resulting gas is withdrawn by the compressor and compressed to a higher pressure. It is then discharged into the condenser, where cold water causes it to condense, after which it returns to the receiver, to again enter the evaporating coil. As will be seen, this is identical with the ammonia refrigerating cycle, but the pressures are far higher in the CO_2 systems. This is because liquid carbon dioxide has a higher vapor pressure than does ammonia.

As the purpose of the compressor is to raise the gas pressure above its vapor, or boiling pressure, at the temperature existing in the condenser, the pressure gauge in the compressor unit indicates up to 1,000 lb. per square inch and more.

Such pressures, however, are not dangerous, if the equipment is properly designed. Even if a leak developed, no explosion would result, for carbon dioxide is inert and will not combine with air to form an explosive mixture.

The tendency of a gas to leak depends upon the pressure and upon the pressure of the space into which it may leak. As the suction pressure of an ammonia machine is, say, 30 lb. gauge and the discharge around 150 lb., the leakage by the piston is far less than if CO_2 were being compressed in the same machine from a suction of 320 lb. to a discharge pressure of 1,000 lb. To reduce leakage, the piston of the CO_2 compressor must be made as small in diameter as possible, which calls for a cylinder with a long stroke and small bore. A long-stroke machine is likewise dictated by the requirement that the bearing pressures and the weight of the moving parts be kept as low as possible.

Formerly such compressors were all horizontal, with the piston rod passing through a stuffing-box. This must be tight enough to prevent leakage of the 1,000-lb. gas into the atmosphere. As the rod always warms up when the machine is operating, as soon as the compressor is shut down the engineer must tighten the gland to compensate for the shrinkage of the rod. The constant attention of the engineer is needed to adjust the stuffing-box to the varying operating temperatures.

A vertical inclosed compressor using a removable cylinder line is shown in Fig. 22. The piston is of the stepped type, with the suction gas entering the space formed by the two diameters. The gas passes up through a slot into the hollow piston to enter the cylinder space through a poppet valve in the centre of the piston crown.

The lower portion of the piston carries the crosshead pin, so the side thrust is not imposed upon the wall of the compressing cylinder.

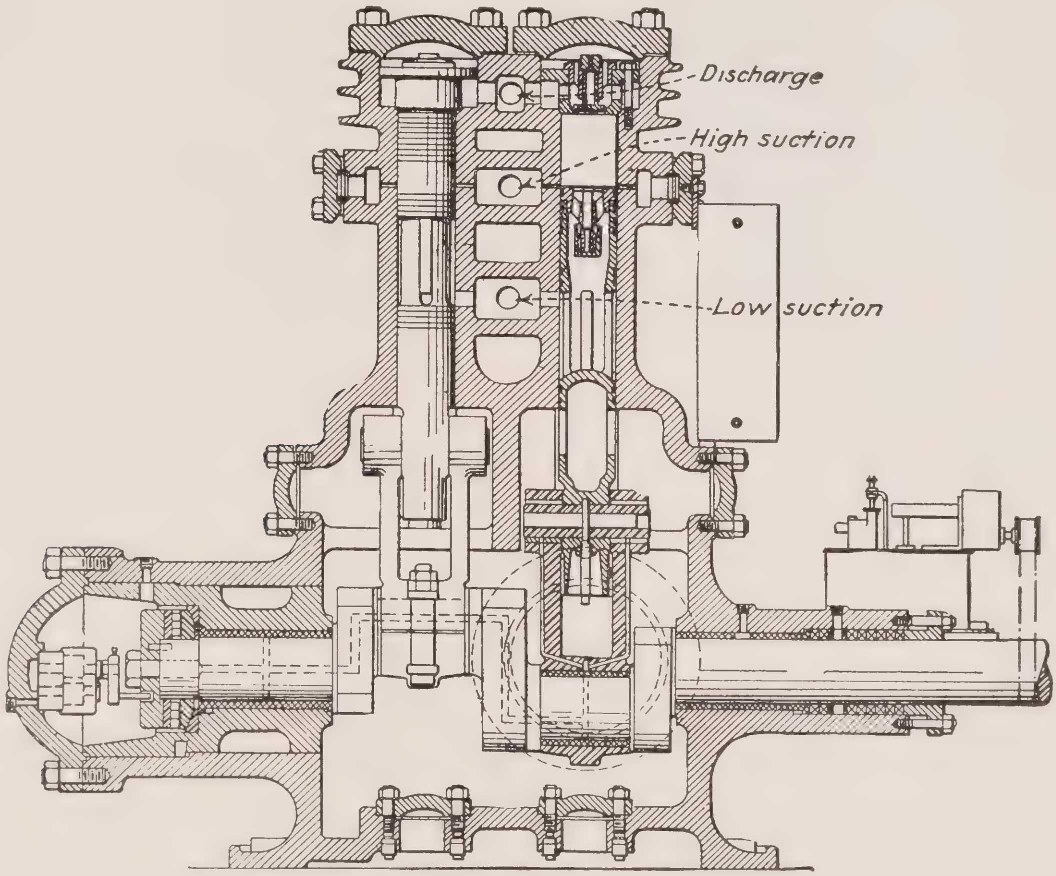


Fig. 22. Sectional view of carbon dioxide vertical compressor.

In Fig. 23 is shown a second design of compressor embodying an extremely long piston supported at the lower end by guides machined in the frame casting. This machine is arranged for dual compression, whereby after low-pressure gas has entered the cylinder through the valve in the piston crown high-pressure suction gas enters through a row of ports uncovered by the piston at the end of its suction stroke. Snap rings seal the piston against leakage into the crankcase, but the frame is designed to withstand the full cylinder pressure.

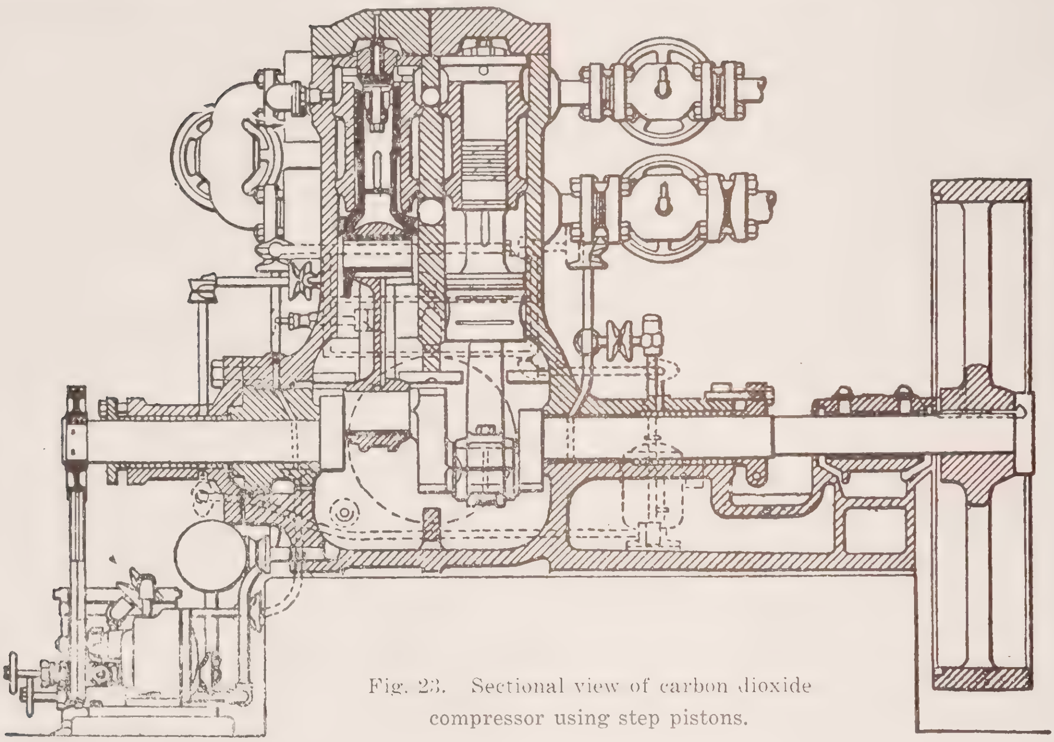


Fig. 23. Sectional view of carbon dioxide compressor using step pistons.

A vertical design in which a stuffing box is used is shown in Fig. 24. It will be noticed that a piston rod and crosshead are used, so that side thrust is not experienced by the piston. A long lantern and an appropriate number of rings make up the rod stuffing box. Any leaks from the cylinder pass into the lightly sealed box at the top of the frame. Consequently, no mixing of lubricating oil and carbon dioxide takes place in the crankcase.

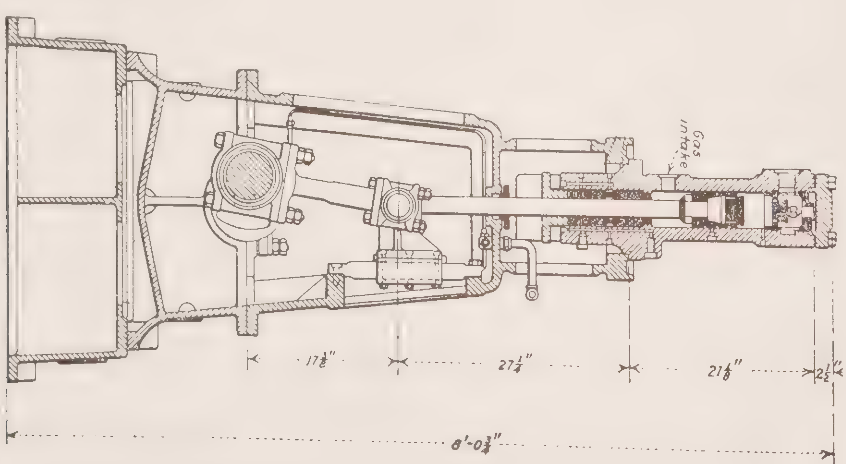


Fig. 24. Sectional view of three cylinder carbon dioxide compressor.

ABSORPTION SYSTEM

The absorption system is not popular in Ontario as very few such systems are installed. Whatever the reason, it is not that this system is less efficient than the compressor system. If there is sufficient exhaust steam which might otherwise go to waste, the absorption system is the more economical. For low temperatures the absorption system can compare very favourably with the compression system.

Aqua Ammonia

All liquids have a certain affinity for gases, with the result that a liquid will absorb a certain amount of any gas with which it is in contact. The amount varies greatly with different substances. Water and ammonia have a very great affinity and a proportionately large quantity of ammonia can be absorbed in water. The quantity of ammonia absorbed differs with changing conditions of the water as to temperature and pressure. The cooler the water the more ammonia it will absorb, and the higher the pressure the more gas the water will absorb. The union of ammonia gas and water creates heat. The mixture of ammonia and water is known as aqua ammonia, in distinction to liquid ammonia, the latter being pure ammonia in a liquid state, made by subjecting the gas to a high pressure and low temperature.

The boiling temperature of aqua ammonia is lower than the boiling point of water and also varies with the percentage of ammonia contained in the solution. The following table gives the temperatures at which aqua ammonia boils at atmospheric pressure:

Per Cent Water	Per Cent Ammonia	Boiling Temperature F.
100	0	212
90	10	155
80	20	117
70	30	83.8
60	40	53.5
50	50	26.9

For other pressures and corresponding temperatures, see table, page 64.

The great affinity of water and ammonia has made it possible to use this phenomena in the process of refrigeration by what is known as the absorption system. In the process, aqua ammonia consisting of about 30 per cent ammonia by weight and 70 per cent water is used.

Percentage of Ammonia

It is important that the percentage of ammonia in the aqua ammonia be known. This is obtained by ascertaining the specific gravity of the liquid. The specific gravity of aqua ammonia is less than that of water and the larger the percentage of the ammonia present, the less is the specific gravity.

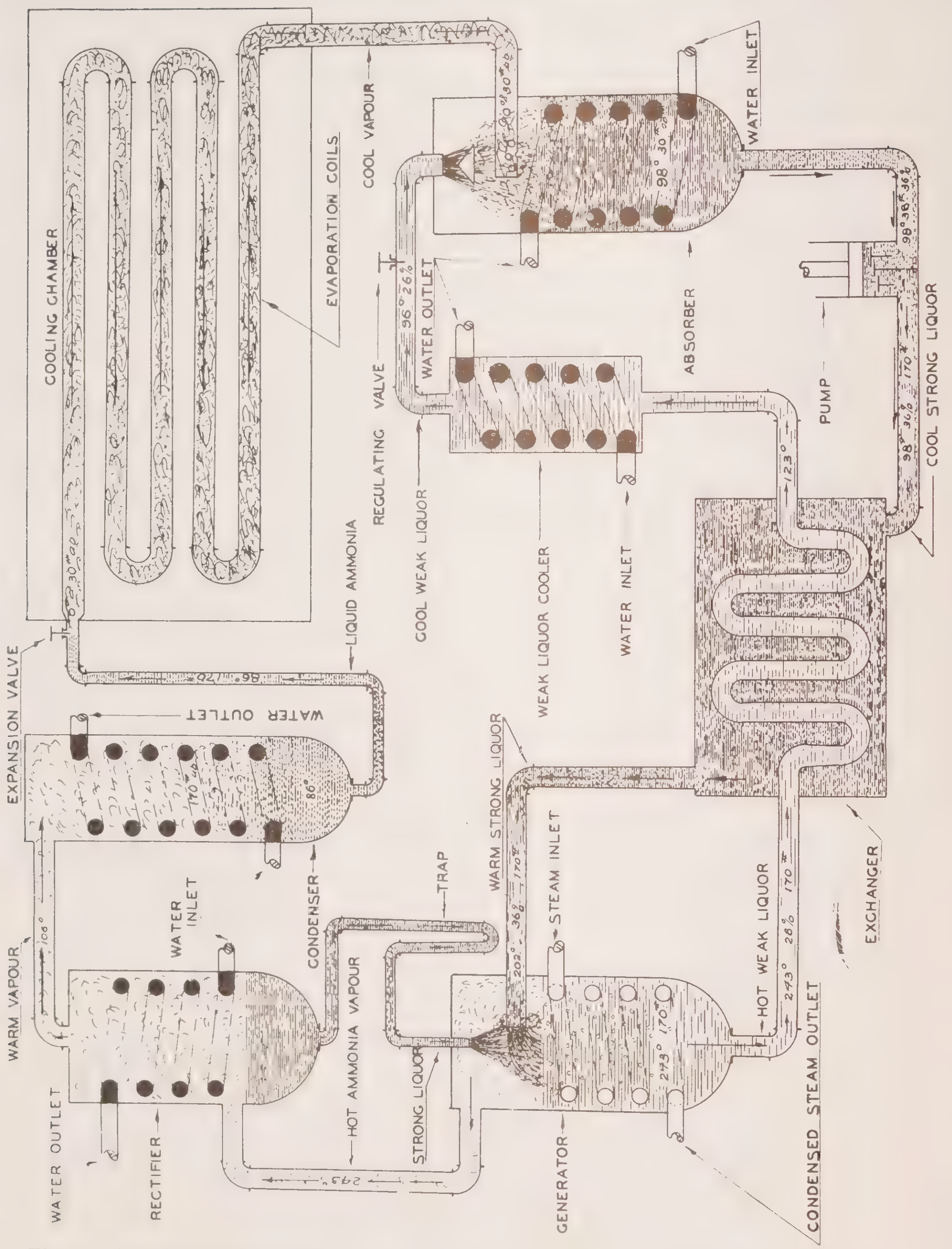


Fig. 25. Diagrammatical sketch showing the path of the gas in an ammonia absorption system.

Specific Gravity

The specific gravity is ascertained by the use of the Beaume hydrometer. When the hydrometer is placed in a vessel containing pure water, the scale will read ten. For substances lighter than water, the formula:

$$\frac{140}{\text{Specific gravity}} - 130 \text{ is used.}$$

The Absorption Cycle

In Fig. 25 we show a diagrammatical sketch of an absorption system. In the vessel known as the generator is a solution of strong liquor (water strongly saturated with ammonia gas). This vessel is subjected to outside heat, which in most cases is supplied from exhaust steam from engines.

When the strong liquor is heated, the ammonia gas with a portion of steam is driven off. This mixture rises and flows into the rectifier which is kept cool by flowing water. The mixture of gas and steam is cooled sufficiently to condense the steam and the condensate is returned to the generator through a drain and trap, while the dry ammonia gas flows to the condenser, where it is further cooled until it liquefies. The liquid ammonia now flows by gravity through a pipe past the expansion valve, and reaching the evaporator it evaporates, and in doing so extracts heat from the surrounding brine. As it evaporates it rises and flows in the form of a gas to the absorber where it mixes with weak liquor (water and weak solution of ammonia) and thereby becomes a strong liquor.

It is then pumped through the exchanger back to the generator from whence it started.

When the ammonia gas is driven off in the generator, it leaves behind weak liquor. The weak liquor is at the same time allowed to flow by its own circuit, from the generator to the absorber, where it again meets with the gas and absorbs the gas from the strong liquor, before it returns to the generator as already outlined.

In its passage to the absorber, it passes the exchanger, where it comes in contact with the pipes carrying the strong liquor. In the exchanger the weak liquor gives up a portion of its heat to the strong liquor and thereby loses a portion of its heat. The strong liquor being heated, requires less heat when it enters the generator and the weak liquor being cooled, requires less cooling water when cooled in the weak liquor cooler, before entering the absorber.

CO_2-AMMONIA SYSTEM FOR LOW-TEMPERATURE REFRIGERATION (Power)

Carbon dioxide evaporates at extremely low temperatures at suction pressures much above atmospheric. This characteristic led to the application of CO_2 to refrigerating purposes at low temperatures, but the extremely high condensing pressures usually encountered discouraged the adoption of either the straight or the compound CO_2 compression systems for low-temperature quick freezing plants. It was then discovered that evaporating ammonia to condense the CO_2 gas made the operation more feasible. Naturally the low head pressure under which the CO_2 operates in this type of system has

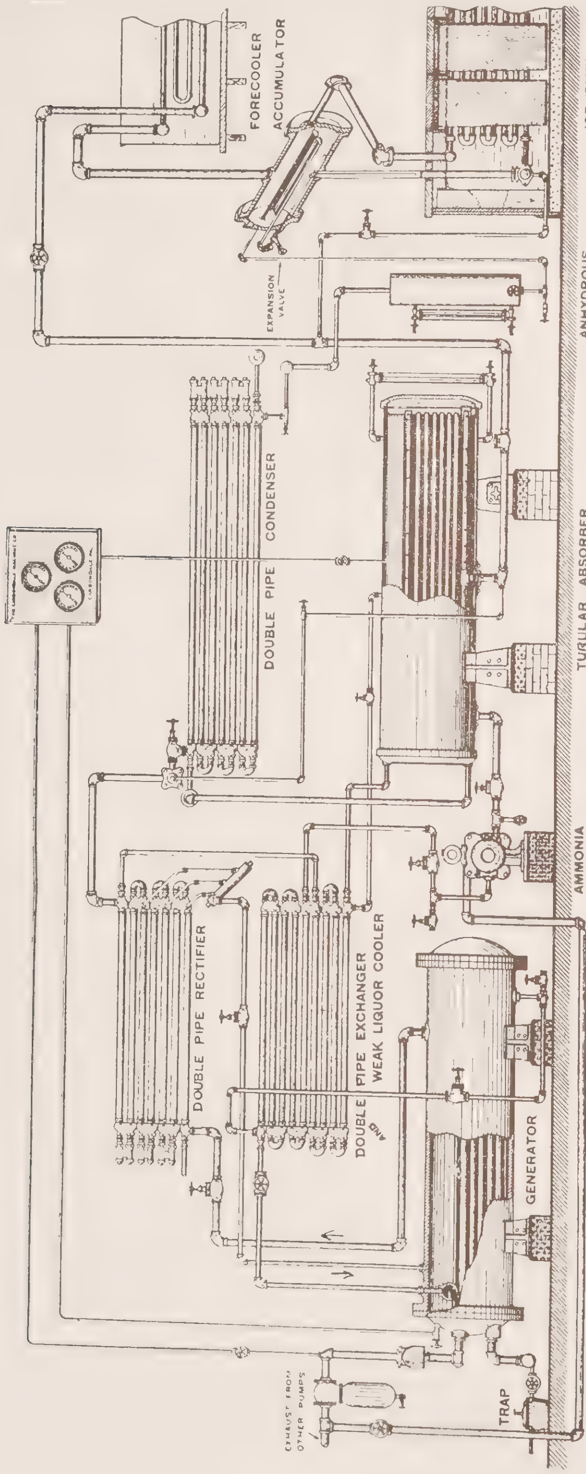


Fig. 26. Diagrammatical lay-out of an ammonia absorption system.

encouraged still lower suction pressures, with lower compression ratios than are found in compound-compression plants employing the gas.

The split-stage system outlined in Fig. 27 operates as two distinct refrigeration systems. The low-pressure CO_2 gas is drawn into the CO_2 compressor and is discharged into the condensers, which are cooled by direct expansion of ammonia. The suction of the ammonia compressor removes the ammonia gas evaporated in cooling the CO_2 and discharges it into the usual ammonia high side. The ammonia liquid level in the CO_2 condensers is maintained by float control, thus insuring flooded conditions and a relatively low temperature difference between the CO_2 and the ammonia. This difference depends on the amount of surface, but can be maintained between 10 and 15 deg. F. with 8½ sq. ft. of surface per ton of refrigeration when the equipment is properly designed. One familiar with CO_2 is aware that from 60 to 65 lb. gauge is the triple point where it is possible to have a liquid, gas or solid. Brine Temperature as low as —45 deg. or —50 deg. F. have been maintained without trouble from this source.

The CO_2-ammonia system has several other advantages over the compound CO_2 system. The low condensing pressure must be mentioned first, as this is one of the most important. High CO_2 pressures, such as 1,000 or 1,200 lb., are not impracticable, but they are uneconomical and inconvenient, resulting in loss of gas at times, especially when the water temperatures are high. The saving in power of the split-stage system must be considered an attraction. High-pressure equipment must be of a heavy design and very often of expensive material.

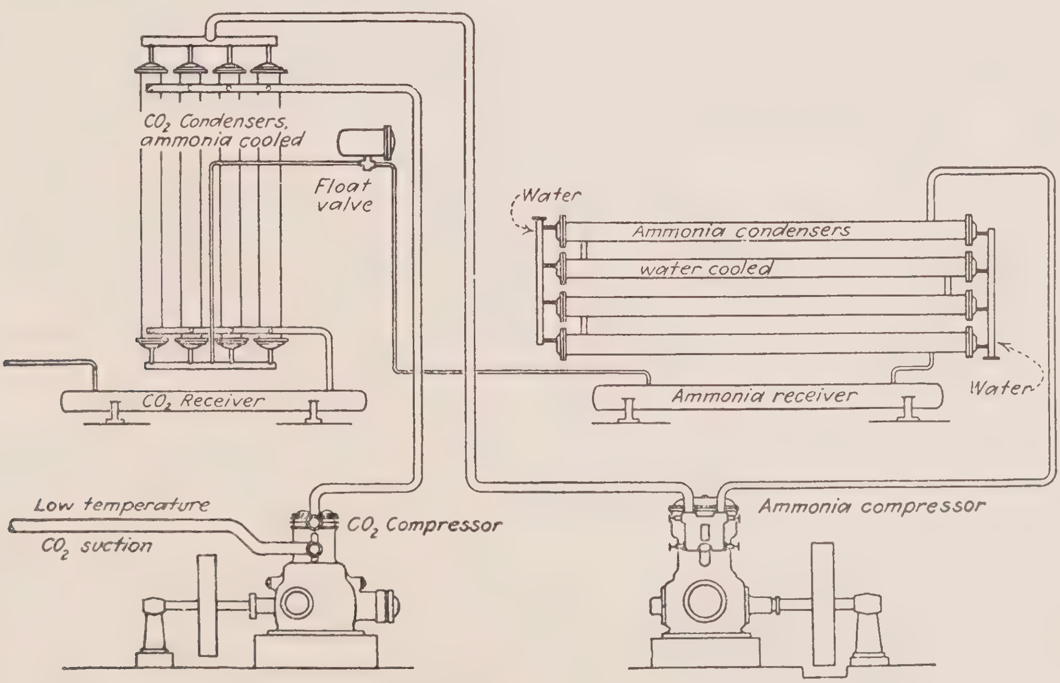


Fig. 27. Diagram of a carbon dioxide ammonia split-stage system.

When using 70 to 75 deg. F. water, which is commonly encountered in the summer time, the split system will operate on approximately 15 per cent less power than the compound CO_2 system. Often the ammonia system, in addition to condensing the CO_2 gas, is used for other cooling purposes. This offers flexibility not available with the CO_2 compound system. The intermediate pressure of CO_2 compound compression is often 350 lb. or more, corresponding to a temperature of 10 deg. or higher. This would not carry the low-temperature storages generally required for frozen goods. To decrease the ratio of low-stage compression would raise the horsepower per ton and consequently cut down the saving to be made over straight CO_2 compression.

Some may wish to compare the split-stage system with booster-compound ammonia systems. In the latter system the ammonia low suction, operating at 15 to 20 in. vacuum is compressed by a booster or low-pressure ammonia compressor up to 0 lb. or higher, then is raised by compound compressors to the condensing pressure. Theoretically, this system is advantageous and shows a small saving in power over the split-stage system; practically it introduces complications similar but of a nature opposite to those of the CO_2 compound system. Operating under such a vacuum, it is obvious that leakage of air may be a problem, and unless stuffing boxes and joints are well guarded, the condensing pressure will rise, causing an increased power consumption. The split-stage system has no vacuum troubles, since it operates above atmospheric pressure. The condensing pressure of the CO_2 is not much above the ammonia condensing pressures encountered in tropical countries.

It has often occurred to the writer that split-stage quick-freezing plants could also manufacture the frozen CO_2 required for their shipment of goods. The power requirements per pound of frozen CO_2 for a split-stage system, is no more than that required by the ordinary frozen CO_2 plant. The only additional investment over the cost of the low temperature freezing and cold-storage machinery would be for a CO_2 booster compressor, liquid coolers, intercoolers and snow machine. The frozen CO_2 could be manufactured as required, avoiding losses during storage and transportation. Of course the additional investment would be tied up in equipment used infrequently, but the cost of CO_2 would no doubt be the deciding issue. The help required to produce this frozen CO_2 would not exceed the usual man-power required around a quick-freezing plant where the CO_2 is not frozen.

Influencing Factors

The cost of CO_2 liquid, location of plant, cost of labour and power, kind of product and amount to be quickly frozen, amount of CO_2 ice to be made and size of storages and temperatures are factors that decide the economy of making CO_2 ice to use in shipments of the frozen products. The production requires approximately 10 h.p. per pound per minute with the usual split-stage system based on receiving the CO_2 gas at a low pressure. This will be lowered nearly 20 per cent when receiving bottled liquid, which would furnish the usual make-up for the split-stage system. Power consumption would vary according to the requirements of any particular plant and depends to a great extent on the water available.

Automatic control for low-temperature rooms operating under the split-stage system gives a positive-pressure cycle. With ammonia working under a vacuum, automatic apparatus is difficult to keep adjusted for continuous results. Pressure switches, for example, have been devised for vacuum operation and are usually sensitive, but their range of usefulness is limited. Temperature control can be used, but here again the operation must be carefully guarded lest the feed of ammonia become restricted too greatly and the compressor operate at too low a pressure, which would be uneconomical. Feeding too fast raises the pressure, with a corresponding rise in temperatures and the possibility of carrying liquid over to the compressor.

Automatic Control

The split-stage system operates under a pressure enabling magnetic valves, float controls, automatic expansion valves and pressure switches to give best results. The shafts of the CO_2 and ammonia compressors can be coupled together and driven by either a synchronous motor mounted on a shaft or by a belt wheel. An outboard bearing carries the weight of the wheel or motor and the coupling load. Since both machines are tied together, the starting of the motor places the entire system in operation.

The use of synchronous motors eliminates belt drives and provides more positive operation. When arranged with an unloader, both compressors come up to speed before being subjected to the load. After synchronous speed has been reached, both loads are gradually applied. This unloader works equally as well with hand starters, since a press on the "start" push button station unloads the machine and starts the motor, without the necessity of using the hand operated by-pass valves. Synchronous motors generally provide the most economical drive, although high-torque squirrel-cage motors with V-belt drives give excellent results.

CONDENSERS

As already stated the object of the condenser is to extract the heat from the compressed gas until it becomes a liquid. The refrigerant is now in a condition that when expanded it can collect from its surroundings, heat equivalent to its latent heat while the cooling water has carried heat off to the sewer.

There is quite a large variety of condensers on the market which may be roughly classified as:

(1) Stand Atmospheric Condenser.
(2) Bleeder Type Atmospheric Condenser.
(3) Flooded Type Atmospheric Condenser.
(4) Double Type Condensers.
(5) Submerged Type Condensers.
(6) Shell Type Condensers.

STANDARD ATMOSPHERIC CONDENSER

This condenser is the simplest and easiest to construct. It consists as shown in Fig. 28 of a number of pipes placed horizontally one above the other on a stand. Each pipe is connected to the next one higher up by a special U fitting. The gas enters the top pipe and travels through it to the next lower pipe, until it reaches the end of the bottom pipe, whence it is led off in a liquid form.

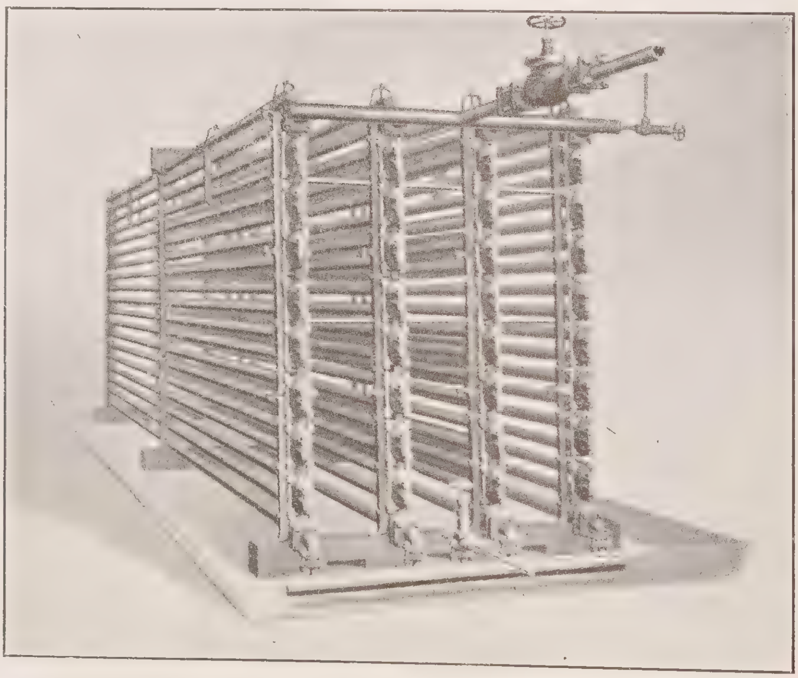


Fig. 28. An atmospheric or surface type of ammonia condenser.

Above the coil of pipes is a trough supplied with cooling water as seen in Fig. 1. The cooling water passing through a row of small holes in the bottom of the trough sprinkles down over the pipe coils carrying away the heat.

A disadvantage of this condenser is that the hot gases and the cold water are at the top of the condenser and the heated water and cooled gases are at the bottom which is the outlet of the ammonia. This is a condition just the reverse of what it should be, as the cooled gases should have the coldest water to still further cool them. However, if a liberal supply of cooling water is used, the condenser will give good results.

Bleeder Type Condenser

The difficulty experienced in the standard type just discussed in not having the water flow in the opposite direction to the gas, is overcome in the Bleeder Type by having the gas enter the condenser at the bottom and flow upward. As the gas condenses to a liquid in the coils it is drained off by having a bleeder pipe attached to the end of each second or fourth pipe which leads the ammonia down to the receiver. This type is shown in Fig. 3.

Flooded Atmosphere Type

Another atmosphere type of condenser is known as the flooded type. In this condenser all the gases enter the bottom of the condenser as in the bleeder type, but upon entering,

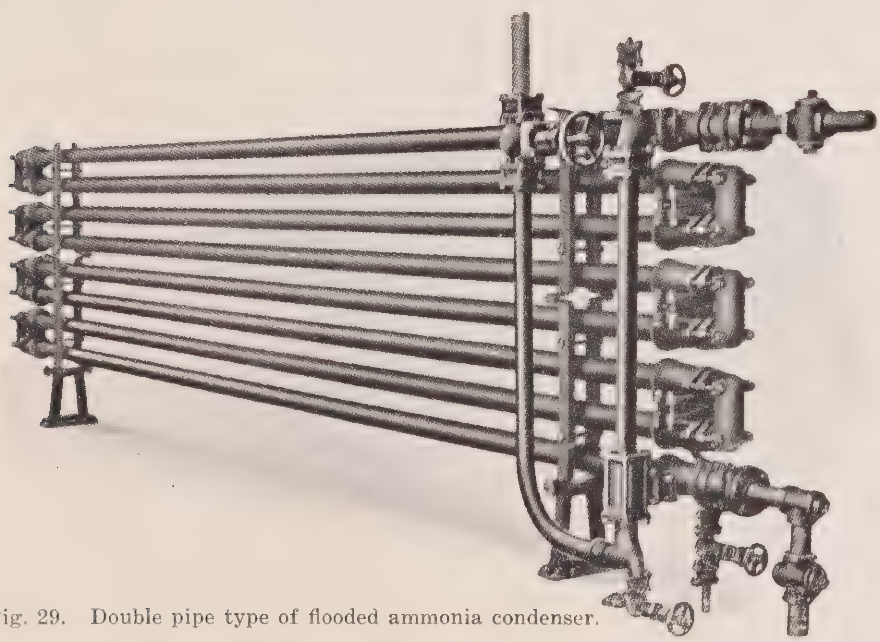


Fig. 29. Double pipe type of flooded ammonia condenser.

the gases are mixed with a regulated portion of liquid returned to the condenser through a nozzle. The nozzle is of such shape and proportion as to create a high velocity which is sufficient to carry the liquid and gas which enters the bottom of the condenser through all

the piping to the top of the condenser. By this time the gases are condensed and are led off to a receiver at a temperature almost as cool as the cooling water. Fig. 29 is a type of the flooded type condenser. It is claimed for this condenser that compared with the standard atmosphere type a lesser number of coils are required to give the same cooling effect.

Submerged Type Condensers

This type of condenser consists of a series of coils placed in a tank. The gas flows through the coils from top to bottom and the liquid is drained off to a receiver at the bottom. Water enters the bottom of the tank, filling it, and is drained off at the top.

The drawback to this system is the slow circulation of the cooling water.

Shell Type Condensers

A vertical tubular condenser is shown in Fig. 30. It consists of a forge-welded shell with flared ends and a heavy tube sheet riveted to each end. The tubes are expanded into the heavy tube sheets. The gas inlet is near the top of the condenser at the point A, the feed is taken off at B and there is also an equalizing line C provided. In addition, there are two purge valves, G at the top and E below the level of the top gauge glass, for eliminating air and foul gases. The gauge glass D is for the purpose of ascertaining the liquid level, as the condenser is frequently used as an anhydrous receiver. Oil may be drained from the equalizing line. These condensers are made in units of 50 tons and larger, and it is possible to so design a plant that one or more units are used to give the necessary

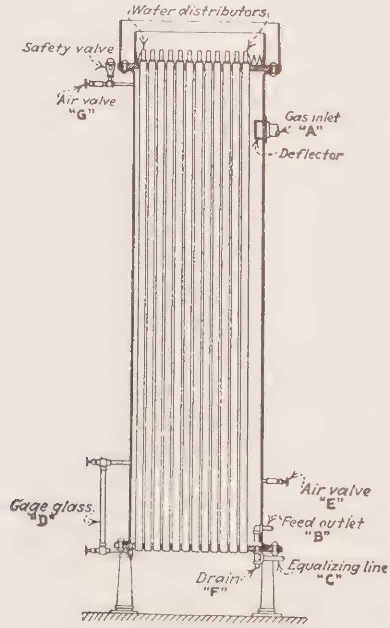


Fig. 30. Cross section of shell and tube condenser.

capacity. The hot gases from the compressor enter through the line A, pass into the shell and circulate around the tubes of the condenser. This is accomplished by means of a deflector on the inside of the shell. This gives the incoming gas a rotary action which sweeps around the side of the shell, increasing the efficiency of the surface. The water enters the outer chamber at the top of the condenser and passes through the distributing slots into the tube chamber where it comes in contact with the various distributors and is carried down through the tubes.

The one objection to this type of condenser is that it is not counter-current, but parallel flow. The transmission through the tubes is so good, however, that it is possible to have the liquid cooled to within five to eight degrees of the temperature of the outlet water, which is about all that can be expected of any type of condenser.

Liquid Receiver

Attached to the bottom of condensers is a tank into which the condensed gases are led. This tank, known as a receiver, acts as a storage tank for the liquid. It is always desirable that the receivers used with the double pipe condenser have a large capacity, as the storage capacity of the condenser is relatively small.

The receiver is subject to high pressure as it is located on the discharge side of the compressor and therefore must be built of sufficient strength to withstand this pressure with a liberal factor of safety.

They are commonly tested to about 500 pounds hydrostatic pressure for ammonia. Of course, for carbon dioxide the pressure required would be much greater.

The usual construction of the tank is shown in Fig. 31.

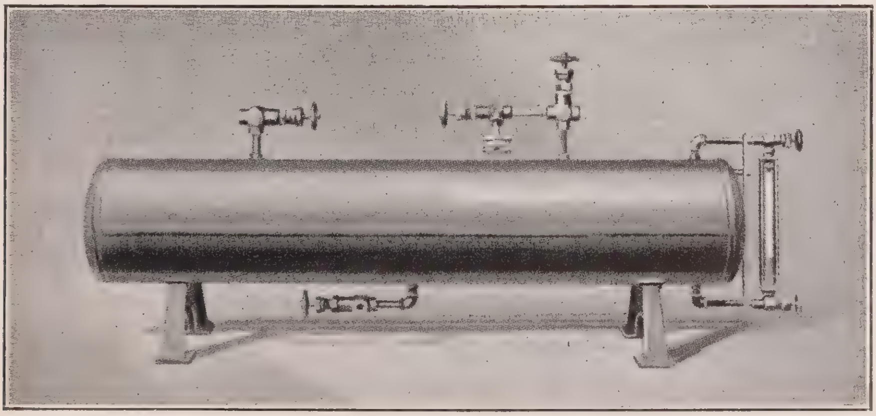


Fig. 31. Ammonia receiver.

It is built of heavy wrought iron or steel, with welded heads and furnished with inlet and outlet valves, and, in addition, a charging valve is placed on the outlet pipe for charging the system with a fresh supply of liquid.

A drain is also placed on the bottom of the tank for purging purposes.

Receivers are built both horizontal and vertical, and are usually equipped with gauge glasses for indicating the quantity of refrigerant in the system.

Pipe Fittings

The working pressure of the different refrigerants under ordinary working conditions are approximately as follows:

Carbon dioxide—1,025 pounds.
Ammonia—155 pounds.
Methyl chloride—83 pounds.
Sulphur dioxide—50 pounds, and
Ethyl chloride—13 pounds.

Should the condenser cooling water fail for any reason, the pressure could easily increase much beyond the figures given. Since refrigerants are, with the possible exception of carbon dioxide, expensive and as all the gases mentioned have a suffocating effect and are dangerous to human life, it can readily be seen that the piping, pipe fittings and joints must be strong and carefully fitted, especially in cases where the refrigerants work under high pressure.

Copper gaskets should never be used for joints when ammonia is the refrigerant, because the ammonia has a corrosive effect on copper. There should rather be used, lead, rubber or asbestos gaskets.

Extra heavy steel piping is used on the discharge side of carbon dioxide and ammonia compressors.

Unlike a small leak in a steam or water line which in time will likely "take up", the operator will find that with gas it will gradually get worse.

A common practice is to paint the thread of pipe with a mixture of litharge and glycerine, but a much more satisfactory joint can be made by tinning the thread and screwing the fitting in place while hot. This latter method, however, entails much work.

Joints are made either by couplings or flanged unions. Flanged unions are much to be preferred to couplings.

The suction line may be of standard pipe and fittings.

Valves and fittings used are extra heavy and made of steel. The larger sizes are flanged, while the small size may be of the threaded type.

Pipe Hangers

It is very important that all piping be well supported and braced, prohibiting as far as possible any vibration which may cause a joint to leak.

Fig. 33 shows variety of pipe hangers and supports.

Direct Expansion System of Cooling

There are two methods of using the cooled gases of the refrigerating system, one being known as the direct system and the other as the brine system.

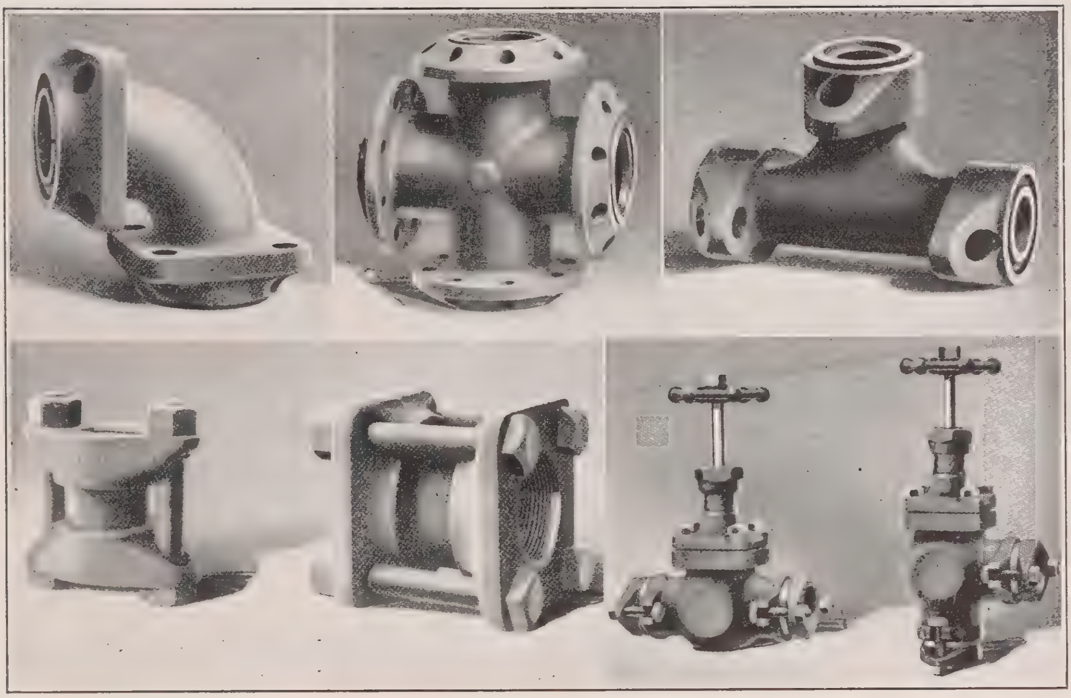


Fig. 32. Pipe fittings used with refrigerating systems.

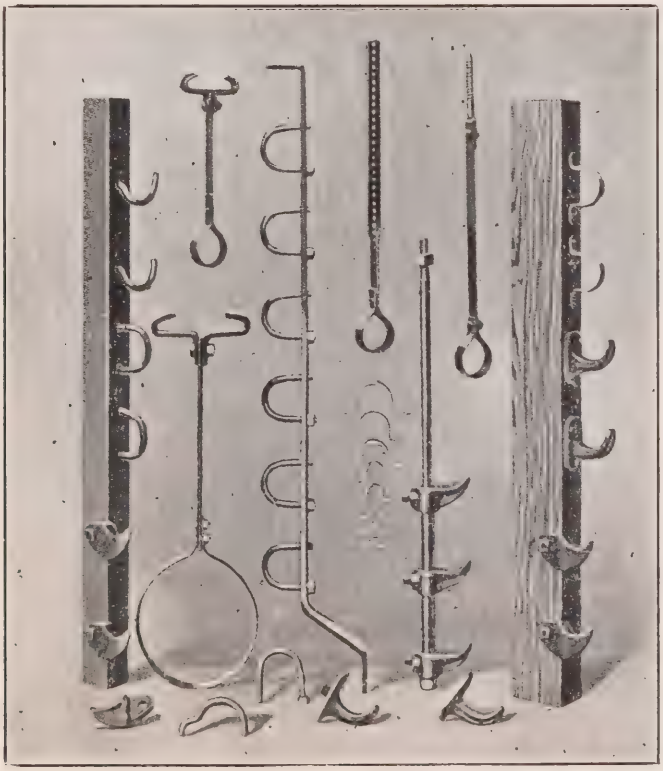


Fig. 33. Pipe hangers.

In the first, the gas flows direct from the receiver through piping and expansion valve to the evaporator. The evaporator consists of coils of pipes hung to the side walls or ceiling of the room to be cooled. There may be several branches from the receiver, each having its own expansion valve running to as many different rooms. Suction lines are united into one common header and return to the compressor. The temperature of the room to be cooled is regulated by the amount of opening of the expansion valve.

The direct system is cheaper to install than the brine system as less piping is required, and probably more economical as there is a large surface exposed to the surrounding atmosphere, in the brine tank. Also, no brine pump is required with the direct system.

Brine System

In the brine system, the evaporating coils are placed in a vessel containing brine. As the refrigerant evaporates in the coils, it takes heat from the brine. The cooled brine is then pumped from the tank, through the coil in the room to be cooled, where it absorbs heat from the room in which the coils are placed, after which it flows back to the tank to be cooled again.

The brine cooler may be of the shell type, containing tubes. The brine is made to flow through the tubes while the refrigerant surrounds them, or, the cooler may be of the double pipe system. During operation care must be taken that the brine does not freeze and block the system.

This system is more elastic than the direct system and the temperatures desired in each room can be more easily controlled by regulating the quantity of brine flowing to each room. This is important, as different substances kept in storage plants require different temperatures, as for instance, eggs keep best at a temperature of near 36° Fah., while for butter the best temperature is near 20° Fah.

Other advantages of the brine system are that the refrigerant is confined entirely to the compressor room and has no great length of pipes and joints that may leak, and that, if the brine tank is of considerable size, the compressor may be shut down at any time for repairs or other reasons, while the brine pump continues to circulate the brine through the different cooling rooms and keeps them at the temperature required.

Hold-over and Congealing Tank

Particularly in small plants of the direct expansion system type, it may be inconvenient to operate the compressor continuously. To overcome this difficulty, a hold-over tank, or in other cases, a congealing tank is frequently installed. In the hold-over system a tank containing a solution of brine is installed in the room to be cooled and a portion of the cooling coils are placed in the tank. While the compressor is in operation it is not only cooling the room but also cooling the brine. When the compressor is shut down the brine absorbs heat and keeps the room cool.

The congealing tank is almost the same thing except that the brine is weak and during the time the compressor is in operation the brine freezes to a more or less solid mass. When the compressor is shut down the frozen brine absorbs heat equal to its latent heat from

the room, thereby keeping the room cool. There are a number of different methods of making use of this system but on the whole the principle is the same.

Brine

Brine is water with some kind of salt dissolved in it.

The brines commonly used in refrigerating plants are : sodium chloride (common salt), calcium chloride and magnesium chloride.

Of the three salts, calcium chloride is the one generally used as it has less corrosive effect. The object of the salt is to lower the freezing point of the liquid.

The solution of calcium chloride has a lower freezing point than sodium chloride of the same density, while magnesium chloride has a still lower freezing point.

The properties of the salt solution are given in tables on page 65.

Ice Making

In the manufacture of artificial ice, tanks of a size depending on the quantity of ice to be made, are installed. These tanks may be made of wood, steel or concrete, and are well insulated all round and fitted with insulating lids.

In the tanks are placed coils of pipe which are in reality the evaporating coils of the refrigerating system. The tanks are fitted with suitable racks for holding cans. The tank is nearly filled with brine. On the brine cans are set, filled with water which is to be frozen into blocks of ice.

The operation is as follows: the liquid refrigerant is allowed to flow from the receiver into the evaporator which is surrounded by brine and draws heat from the brine until its temperature is below that of freezing water. The cold brine, in turn, draws the heat from the water in the cans which, reaching a temperature of 32 degrees, begins to freeze, first about the outside and gradually solidifies until all the water is a solid block of ice.

To increase the rapidity of freezing, the brine is kept in motion by an agitator which causes fresh cool brine to be continually in contact with the outside of the cans.

We have noticed that artificial ice is sometimes of an opaque nature and of whitish color. There is a false impression among customers that this opaque ice is not of as high quality as the clear ice although as a matter of fact, the cooling qualities of each are the same.

Manufacturers try to avoid making the opaque ice as it does not sell as well.

The cause of the opaqueness is due to the fact that all undistilled water contains a certain amount of air dissolved in it. When the water is in process of freezing, the particles of forming ice lock the air within themselves. To overcome this it is now customary to keep the water in constant agitation while freeezing so that the ice cannot surround the air.

This is accomplished by air pressure. A pipe is inserted in the water to near the bottom of the can and compressed air forced through the pipe which, in rising, keeps the water in constant commotion. Sometimes the air passage is fastened to the outside of the can.

Ice cans are made of a form shown in Fig. 34.

When the water in the can is frozen solid, the can is removed from the brine tank and after being heated sufficiently to loosen the ice from the can, it is placed on a can dumper and the ice removed. The can is now ready for refilling and the process repeated.

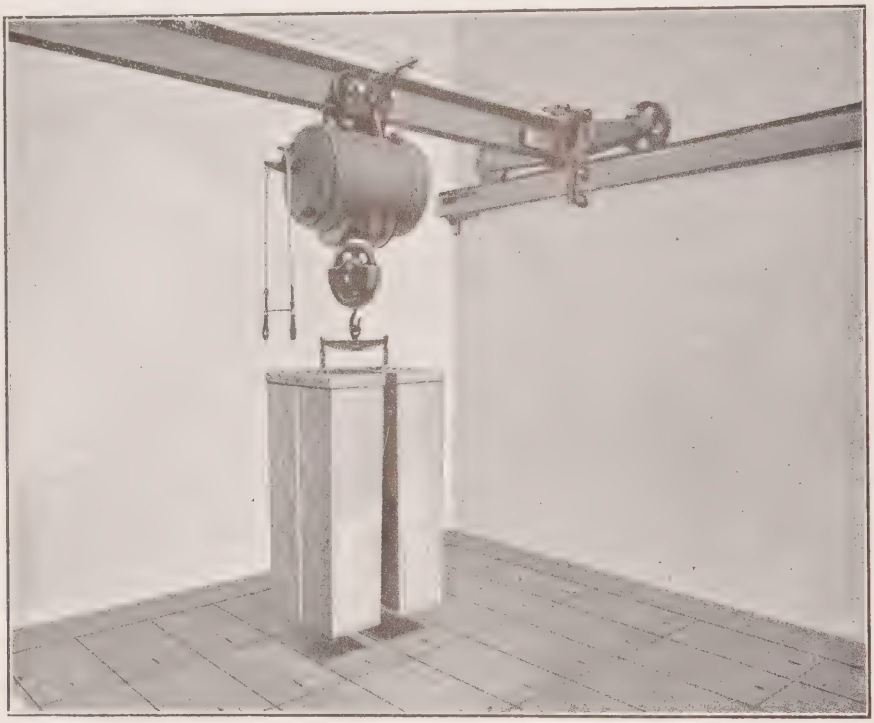


Fig. 34. Ice cans.

Dry Ice

Dry ice is carbon dioxide (CO_2) in a frozen state. The CO_2 gas is a by-product in some industrial plants—take the brewery process for instance and from these plants large quantities of the gas can be obtained. It is also obtained by the burning of coke and having the products of combustion passed through a tower where it is sprayed with a solution of lye. The lye absorbs the carbon dioxide and allows the other gases to pass off. The lye is then heated and the gas driven off and collected.

It is the usual practice to store the gas in a gasometer from which it is drawn to the compressor as required.

Fig. 35 is a diagram of a cycle used in making solid CO_2. The gas is compressed in three successive stages up to the condensing pressure necessary to liquefy the CO_2 at the temperature of the available water. General practice is to obtain water at a temperature of 70 degrees or lower, if possible.

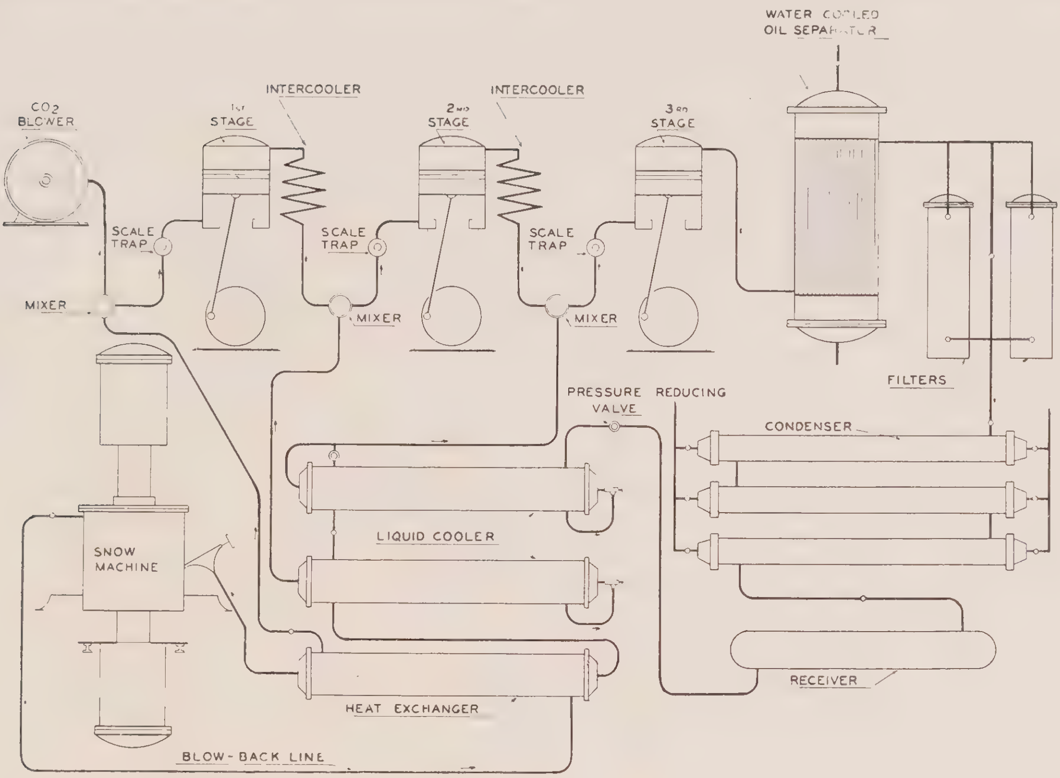


Fig. 35. Diagram of cycle for making solid carbon dioxide, commonly known as dry ice.

Removal of oil is important, since the least trace will make the product difficult to sell. This is accomplished by passing the compressed gas through water-cooled oil separators and filters.

Liquid CO_2 from the condensers is collected in a receiver, which should have ample capacity. A pressure reducing valve in the liquid line reduces the normally high liquid pressure to 600 or 700 lbs., thus eliminating some of the usual losses in gas, and requiring less attention to the setting of expansion valves on the liquid coolers. Liquid cooling gas returns to the suction of the second and third-stage compressors, where it mixes with the gas discharged from the two previous stages. Depending on the cooling water temperature, gas is discharged from the two stages at approximately 95 degrees, after leaving the intercoolers. Part of the coldest water is often run through these coolers on the way to the condenser.

Stage pressures of the compression system depend on the machine ratios employed, but generally run 5 lb. suction to the first stage, 70 to 90 lb. pressure discharge, which is the suction to the second stage. The discharge pressure of the second stage varies between 300 and 350 lb., which is also the suction pressure on the third stage compressor. The discharge pressure of the third stage depends on the water temperature, as previously explained.

It is considered economical practice to employ a blower between the gasometer and the first-stage compressor. In this manner a large volume of gas can be raised to 5 lb. pressure with less horsepower than that required in the first stage of compression.

Mixers are used to reduce the velocity of the cold and warm gases and to obtain as close to a saturated gas mixture as possible. A slight excessive feed to the liquid coolers will provide liquid CO_2 for cooling the compressed gas. The object of cooling the CO_2 liquid so low is to obtain a high conversion of liquid to snow in the snow machine. This conversion averages around 50 per cent with —30 degrees Fahrenheit liquid. The heat exchanger between the last stage of liquid cooling and the snow machine is sometimes employed to remove further heat from the liquid with the cold blow-back gas from the snow machine.

CO_2 liquid is expanded into the snowing chamber of the snow machine at about 60 lb. gauge pressure. The temperature at this pressure is —70 degrees Fahrenheit and is called the triple point because a gas, liquid or solid can exist under this pressure and temperature. As soon as the chamber has filled with snow, the pressure is allowed to fall to approximately 5 lb. gauge, and the snow is compressed to a solid block. Gas liberated in the snow machine, and called "blow-back gas", is taken into the first-stage compressor along with the "make-up gas" from the gasometer.

Solid CO_2 is compressed in the snow machine to 10 in. cubes, weighing from 40 to 50 lb., depending on the density desired. The quantity of solid CO_2 produced depends on the temperature of the liquid to the snow machine and theoretically follows the table below:

Temp. of liquid deg. F.	Per cent solid CO_2	Per cent blow-back gas to first stage
+10	44	56
0	46	54
—10	48.5	41.5
—20	50.5	49.5
—30	52	48

Several modifications of the compressor system permit flexibility and other uses. Compressors can be so arranged that the proper stage ratios are available for manufacturing liquid CO_2. Therefore, liquid CO_2 could be produced at times and stored or bottled for direct sales or to be converted later into solid CO_2. Compressors could be arranged to produce solid CO_2 from liquid at a later time.

Storing of CO_2 gas in gasometers during peak demand on power generating equipment may be economical, since there is more power available during the off-peak period to operate the solid CO_2 plant. This will be governed a great deal by investment cost, since gasometers and space for them may be expensive. Selection of drives is of great importance, so that off-peak reserves can be worked into the full production of solid CO_2 without overload.

Solid CO_2 at atmospheric pressure (in comparison with ice) will absorb nearly twice the heat of melting ice at 32 degrees Fahrenheit and approximately three times the heat

of ice and salt around 0 degrees. No moisture is released by the melting of solid CO_2 and there is naturally no corrosion. This makes it ideal for shipping cold-storage products.

Tons of Refrigeration

The usual method of rating a refrigerating machine as to the work it will do, is to state that it is of a certain tonnage, that is, one machine may be rated as a ten-ton machine and another a twenty-ton machine.

The term "ton" in these cases means the heat required to melt one ton of pure ice at a temperature of 32 degrees, to water at 32 degrees, or it might be expressed as the amount of heat that must be extracted to freeze pure water at 32 degrees.

The commercial "ton" refrigerator is a machine capable of extracting the heat required to freeze one ton of pure ice in 24 hours.

The latent heat of ice is 144 B.T.U., therefore, 144 B.T.U. must be extracted from each pound of water to transform it to ice, or:

$$144 \times 2000 = 288{,}000 \text{ B.T.U. from each ton.}$$

Of course, an ice making machine cannot produce one ton of ice by expending the energy equivalent to 288,000 B.T.U., but will produce somewhere about six-tenths of a ton. The reasons why such is not the case are:

(1) That there are certain unavoidable losses, such as radiation from pipes and other vessels.

(2) Water is not supplied to the machine at 32 degrees, but will probably be around 60 degrees, therefore every pound of water must be cooled from 60 to 32, which is a loss of about 28 B.T.U. per pound, or 56,000 per ton. Again, the brine must have a lower temperature than 32 degrees.

Horse-power Required Per Ton of Refrigeration for Commercial Operation:

H.P.	Tons of Refrigeration	H.P.	Tons of Refrigeration
3	1.05	50	31.2
5	2.1	100	67.2
10	4.7	150	99.2
15	8.9	250	161.1
25	15.6	300	210.3

Latent heat is the quantity of heat that one pound of liquid can absorb while converting to a gas.

A B.T.U. (British thermal unit) is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

(The following tables are given by courtesy of the York Manufacturing Co.)

COMPARISON OF THERMOMETERS

Cent.	Réau	Fahr.	Cent.	Réau	Fahr.	Cent.	Réau	Fahr.
—40	—32.0	—40.0	21	16.8	69.8	62	49.6	143.6
—38	—30.4	—36.4	22	17.6	71.6	63	50.4	145.4
—36	—28.8	—32.8	23	18.4	73.4	64	51.2	147.2
—34	—27.2	—29.2	24	19.2	75.2	65	52.0	149.0
—32	—25.6	—25.6	25	20.0	77.0	66	52.8	150.8
—30	—24.0	—22.0	26	20.8	78.8	67	53.6	152.6
—28	—22.4	—18.4	27	21.6	80.6	68	54.4	154.4
—26	—20.8	—14.8	28	22.4	82.4	69	55.2	156.2
—24	—19.2	—11.2	29	23.2	84.2	70	56.0	158.0
—22	—17.6	— 7.6	30	24.0	86.0	71	56.8	159.8
—20	—16.0	— 4.0	31	24.8	87.8	72	57.6	161.6
—18	—14.4	— 0.4	32	25.6	89.6	73	58.4	163.4
—16	—12.8	+ 3.2	33	26.4	91.4	74	59.2	165.2
—14	—11.2	6.8	34	27.2	93.2	75	60.0	167.0
—12	— 9.6	10.4	35	28.0	95.0	76	60.8	168.8
—10	— 8.0	14.0	36	28.8	96.8	77	61.6	170.6
— 8	— 6.4	17.6	37	29.6	98.6	78	62.4	172.4
— 6	— 4.8	21.2	38	30.4	100.4	79	63.2	174.2
— 4	— 3.2	24.8	39	31.2	102.2	80	64.0	176.0
— 2	— 1.6	28.4	40	32.0	104.0	81	64.8	177.8
0	0.0	32.0	41	32.8	105.8	82	65.6	179.6
+ 1	+ 0.8	33.8	42	33.6	107.6	83	66.4	181.4
2	1.6	35.6	43	34.4	109.4	84	67.2	183.2
3	2.4	37.4	44	35.2	111.2	85	68.0	185.0
4	3.2	39.2	45	36.0	113.0	86	68.8	186.8
5	4.0	41.0	46	36.8	114.8	87	69.6	188.6
6	4.8	42.8	47	37.6	116.6	88	70.4	190.4
7	5.6	44.6	48	38.4	118.4	89	71.2	192.2
8	6.4	46.4	49	39.2	120.2	90	72.0	194.0
9	7.2	48.2	50	40.0	122.0	91	72.8	195.8
10	8.0	50.0	51	40.8	123.8	92	73.6	197.6
11	8.8	51.8	52	41.6	125.6	93	74.4	199.4
12	9.6	53.6	53	42.4	127.4	94	75.2	201.2
13	10.4	55.5	54	43.2	129.2	95	76.0	203.0
14	11.2	57.2	55	44.0	131.0	96	76.8	204.8
15	12.0	59.0	56	44.8	132.8	97	77.6	206.6
16	12.8	60.8	57	45.6	134.6	98	78.4	208.4
17	13.6	62.6	58	46.4	136.4	99	79.2	210.2
18	14.4	64.4	59	47.2	138.2	100	80.0	212.0
19	15.2	66.2	60	48.0	140.0			
20	16.0	68.0	61	48.8	141.8			

$$\text{Fahr.} = 32 + \tfrac{9}{5}\ \text{Cent.} = 32 + \tfrac{9}{4}\ \text{Réau.}$$

Freezing point on Fahrenheit scale is +32 degrees; boiling point, 212 degrees.
Freezing point on Centigrade scale is +0 degrees; boiling point, 100 degrees.
Freezing point on Réaumur scale is +0 degrees; boiling point, 80 degrees.
Of water at sea level at normal barometer pressure (29.9 inch).

The "absolute zero" of temperature denotes that condition of matter at which heat ceases to exist. At this point a body would be wholly deprived of heat and a gas would exert no pressure.

The absolute zero on the Fahrenheit scale is about 461 degrees below zero.
The absolute zero on the Centigrade scale is about 274 degrees below zero.
The absolute zero on the Réaumur scale is about 219 degrees below zero.

An English unit of heat (B.T.U.) is the quantity required to raise one pound of water one degree Fahrenheit. A metric unit of heat or metric caloric (M.C.) is the quantity of heat required to raise one litre of water one degree Centigrade.

CAPACITY OF AMMONIA CONDENSERS

Capacities and Horse Power Per Ton Refrigeration of one section counter-current double pipe condenser, 1¼-inch and 2-inch pipe, 12 pipes high, 19 feet outside water bends, for water velocities 100 feet to 400 feet per minute. Initial temperature of condensing water, 70° F.

High Pressure Constant

Condensing Water				Capacity in Tons Refrig. per 24 hrs.	Condensing Pressure Lbs. per sq. in.	Horse Power per Ton Refrigeration		
Velocity through 1¼″ pipe Ft. per min.	Total Gallons used per min.	Gallons per min. per Ton Refrig.	Friction through Coil Lbs. per sq. in.			Engine Driving Compressor	Circulating Water through Condenser	Total Engine and Water Circulation
100	7.77	1.16	1.69	6.7	185	1.71	.0012	1.7112
150	11.65	1.165	3.05	10.	185	1.71	.002	1.712
200	15.54	1.165	5.08	13.4	185	1.71	.004	1.714
250	19.42	1.18	7.89	16.4	185	1.71	.006	1.716
300	23.31	1.24	11.41	18.8	185	1.71	.009	1.719
400	31.08	1.30	20.51	24.	185	1.71	.016	1.726

Capacity Constant

100	7.77	0.777	1.69	10.	225	.04	.0008	2.0408
150	11.65	1.165	3.05	10.	185	1.71	.022	1.712
200	15.54	1.554	5.08	10.	165	1.54	.005	1.545
250	19.42	1.942	7.89	10.	155	1.46	.009	1.469
300	23.31	2.331	11.41	10.	148	1.40	.016	1.416
400	31.08	3.108	20.51	10.	140	1.33	.038	1.368

Notes: Above tables are based on the Heat Transmission obtained for various velocities of water, as averaged up from York Manufacturing Company's tests on double pipe condensers.

The horse power per ton is for single-acting compressor at 15.67 lbs. suction pressure.

The friction in water pump and connections should be added to water horse power and to total horse power.

PROPERTIES OF SATURATED AMMONIA GAS

De Volson Wood and Geo. Davidson

Gauge Pressure Pounds per Square In.	Absolute Pressure Pounds per Square In.	Temp. Deg. F.	Absolute Tem. Degrees F.	Latent Heat of Evaporation in Thermal Units	Volume of One Pound Vapor in Cubic Feet	Weight of One Cu. Ft. of Vapor in Pounds	Volume of One Pound of Liquid in Cu. Ft.	Weight of One Cu. Ft. of Liquid in Pounds
—4.01	10.69	—40	420.66	579.67	24.38	.0410	.0234	42.589
—2.39	12.31	—35	425.66	576.68	21.32	.0469	.0236	42.337
—0.57	14.13	—30	430.66	573.69	18.69	.0535	.0237	42.123
+1.47	16.17	—25	435.66	570.68	16.44	.0608	.0238	41.858
3.75	18.45	—20	440.66	567.67	14.51	.0690	.0240	41.615
6.29	20.99	—15	445.66	564.64	12.83	.0779	.0241	41.374
9.10	23.80	—10	450.66	561.61	11.38	.0878	.0243	41.135
12.22	26.92	— 5	455.66	558.56	10.12	.0988	.0244	40.900
15.67	30.37	0	460.66	555.50	9.03	.1107	.0246	40.650
19.46	34.16	+ 5	465.66	552.43	8.07	.1240	.0247	40.404
23.64	38.34	10	470.66	549.35	7.23	.1383	.0249	40.160
28.24	42.94	15	475.66	546.26	6.49	.1541	.0250	39.920
33.25	47.95	20	480.66	543.15	5.84	.1711	.0252	39.682
38.73	53.43	25	485.66	540.03	5.27	.1897	.0253	39.432
44.72	59.42	30	490.66	536.91	4.76	.2099	.0255	39.200
51.22	65.92	35	495.66	533.78	4.31	.2318	.0256	38.940
58.29	72.99	40	500.66	530.63	3.91	.2554	.0258	38.684
65.96	80.66	45	505.66	527.47	3.56	.2809	.0260	33.461
74.26	88.96	50	510.66	524.30	3.24	.3084	.0261	38.226
83.22	97.92	55	515.66	521.12	2.96	.3380	.0263	37.994
92.89	107.59	60	520.66	517.93	2.70	.3697	.0265	37.736
103.33	118.03	65	525.66	514.73	2.48	.4039	.0266	37.481
114.49	129.19	70	530.66	511.52	2.27	.4401	.0268	37.230
126.52	141.22	75	535.66	508.29	2.09	.4791	.0270	36.995
139.40	154.10	80	540.66	505.05	1.92	.5205	.0272	36.751
153.18	167.88	85	545.66	501.81	1.77	.5649	.0273	36.509
167.92	182.62	90	550.66	498.55	1.64	.6120	.0275	36.258
183.65	198.35	95	555.66	495.29	1.51	.6622	.0277	36.023
200.42	215.12	100	560.66	492.01	1.39	.7153	.0279	35.778
218.28	232.98	105	565.66	488.72	1.289	.7757	.0281	
237.27	251.97	110	570.66	485.42	1.203	.8312	.0283	
258.7	272.14	115	575.66	482.41	1.121	.8912	.0285	
275.79	293.49	120	580.66	478.79	1.041	.9608	.0287	
301.46	316.16	125	585.66	475.45	.9699	1.0310	.0289	
325.72	340.42	130	590.66	472.11	.9051	1.1048	.0291	
350.46	365.16	135	595.66	468.75	.8457	1.1824	.0293	
377.52	392.22	140	600.66	465.39	.7910	1.2642	.0295	
405.79	420.49	145	605.66	462.01	.7408	1.3497	.0297	
435.5	450.20	150	610.66	458.62	.6946	1.4396	.0299	
466.84	481.54	155	615.66	455.22	.6511	1.5358	.0302	
499.70	514.50	160	620.66	451.81	.6128	1.6318	.0304	
534.34	549.04	165	625.66	448.39	.5765	1.7344	.0306	

One atmosphere in this table is equal to a pressure of a column of mercury .... 29.9 inches high
Specific heat of ammonia gas and vapor at constant pressure 0.508
The same at constant volume 0.3913
Weight of 1 cubic foot liquid ammonia at 32 degrees Fahr. .... 39.108 pounds
Volume of 1 pound liquid ammonia at 32 degrees Fahr. .... 0.02557 cu. ft.
Specific heat of liquid ammonia (Wood) .... 1.12136+0.000438t

PROPERTIES OF AMMONIA LIQUOR
(Starr's Table)

Showing the Relation Between Pressure and Temperature for Solutions of Ammonia in Water of Different Strengths

Line	Per Cent. of NH_3 by Weight and Degree Beaumé	65	70	75	80	85	90	95	100	105	110	115	120	125	Line
1	1	306.3	310.4	314.4	318.2	321.8	325.2	328.5	331.7	334.8	337.8	340.7	343.5	346.2	1
2	1.84-11° B	301.8	306.0	310.0	313.8	317.4	320.8	324.1	327.3	330.4	333.4	336.3	339.1	341.8	2
3	2	300.9	305.2	309.2	312.9	316.6	320.0	323.2	326.5	329.6	332.6	335.4	338.2	341.0	3
4	3	295.6	300.0	303.9	307.6	311.3	314.7	317.9	321.2	324.3	327.3	330.1	332.9	335.7	4
5	3.80-12° B	291.1	295.3	299.3	303.1	306.7	310.1	313.4	316.6	319.7	322.7	325.6	328.4	331.1	5
6	4	290.1	294.2	298.3	302.1	305.6	309.1	312.4	315.5	318.7	321.6	324.5	327.4	330.0	6
7	5	284.8	288.9	293.0	296.3	300.3	303.8	307.1	310.2	313.4	316.3	319.2	322.1	324.7	7
8	5.30-13° B	283.5	287.7	291.7	295.5	299.1	302.5	305.8	309.0	312.1	315.1	318.0	320.8	323.3	8
9	6	280.0	284.1	288.2	291.9	295.5	299.0	302.2	305.5	308.5	311.6	314.4	317.3	319.7	9
10	6.80-14° B	275.4	279.6	283.6	287.4	291.0	294.4	297.7	300.9	304.0	307.0	309.9	312.7	315.2	10
11	7	274.5	278.6	282.7	286.4	290.1	293.5	296.7	300.0	303.0	306.1	308.9	311.8	314.2	11
12	8	269.6	273.7	281.7	281.5	285.2	288.6	291.7	295.1	298.1	301.2	303.9	306.9	309.3	12
13	8.22-15° B	267.4	271.6	275.6	279.4	283.0	286.4	289.7	292.9	296.0	299.0	301.9	304.7	307.2	13
14	9	264.0	268.2	272.2	276.0	279.6	283.0	286.3	289.6	292.6	295.6	308.5	301.3	303.8	14
15	10-16° B	258.7	262.9	266.9	270.7	274.3	277.7	281.0	284.2	287.3	290.3	293.2	296.0	298.5	15
16	11	254.2	258.4	262.4	266.2	268.8	273.2	276.5	279.7	282.8	285.8	288.7	291.5	294.0	16
17	12	249.8	253.9	257.9	261.7	264.3	268.7	272.0	275.2	278.3	281.3	289.2	287.0	289.5	17
18	12.17° B	247.7	251.9	255.4	259.7	263.3	266.7	270.0	273.2	276.3	279.3	282.2	285.0	287.5	18
19	13	244.2	248.4	251.8	256.2	259.8	263.1	266.5	269.6	272.8	275.7	278.6	281.5	284.0	19
20	13.88-18° B	240.5	244.0	248.7	252.5	256.1	259.5	262.8	266.0	269.1	272.1	275.0	277.8	280.3	20
21	14	240.0	243.5	248.2	252.0	252.5	259.0	262.3	265.5	268.6	271.6	274.5	277.3	280.0	21
22	15	235.8	239.3	244.0	247.8	252.0	254.8	258.1	261.3	264.4	267.4	270.3	273.1	275.8	22
23	16	231.6	235.1	239.8	243.6	247.8	250.6	253.7	257.1	260.2	263.2	266.1	268.9	271.6	23
24	16.22-19° B	230.4	234.6	238.6	242.4	243.6	249.4	252.7	255.9	259.0	262.0	264.9	267.7	270.2	24
25	17	227.2	231.4	235.4	239.2	242.4	246.2	249.5	252.7	255.8	258.8	261.7	264.5	267.0	25
26	18.03-20° B	222.8	227.0	231.0	234.8	239.2	241.8	245.1	248.3	251.4	254.4	257.3	260.1	262.6	26
27	19	218.8	223.1	227.0	230.9	234.8	237.9	241.1	244.4	247.4	250 5	253.4	256.1	258.7	27
28	19.87-21° B	215.6	219.8	223.8	227.6	230.9	234.6	237.9	241.1	244.2	247.2	250.1	252.9	255.4	28
29	20	215.2	219.3	223.4	227.1	227.6	234.1	237.4	240.7	243.8	246.7	249.6	252.4	255.0	29
30	21	211.5	215.6	219.7	223.3	227.1	230.4	233.7	237.0	240.1	243.0	245.9	248.7	251.3	30
31	21.75-22° B	208.4	212.6	216.6	220.4	223.3	227.4	230.7	232.9	237.0	240.0	242.9	245.7	248.2	31
32	22	207.5	211.7	215.7	219.5	220.4	226.5	229.8	233.0	236.1	239.1	242.0	244.8	247.3	32
33	23.03-23° B	203.3	207.5	211.5	215.3	219.5	222.3	225.6	228.8	231.9	234.9	237.8	240.6	243.1	33
34	24	200.1	204.2	208.3	212.1	215.3	219.1	222.4	225.6	228.7	231.7	234.6	237.4	240.0	34
35	24.99-24° B	196.5	200.7	204.7	208.5	212.1	215.5	218.8	222.0	225.1	228.1	231.0	233.8	236.3	35
36	26	193.3	197.5	201.6	205.3	208.9	212.2	215.6	218.9	221.9	225 0	237.8	230.6	233.1	36
37	27	190.2	194.3	198.4	202.2	205.7	209.0	212.5	215.8	218.7	221.8	234.7	227.4	230.0	37
38	27.66-25° B	187.6	191.8	195.8	199.6	202.2	206.6	209.9	213.1	216.2	219.2	222.1	224.9	227.4	38
39	28	186.6	190.7	194.8	198.5	203.2	205.6	208 8	212.1	215.1	218.2	221.0	223.9	226.3	39
40	29	183.5	187.6	191.8	195.4	199.1	202.6	205.7	209.0	212.1	215.1	217.9	220.9	223.2	40
41	29.60-26° B	181.4	185.6	189.6	193.4	197.0	200.4	203.7	206.9	210.0	213.0	215.9	218.7	221.2	41
42	30	180.2	184.4	188.4	192.2	195.8	199.2	202.5	205.7	208.8	211.8	214.7	217.5	220.0	42
43	31.05-27° B	177.0	181.2	185.2	189.0	192.6	196.0	199.3	202.5	206.6	209.6	212.5	215.3	217.8	43
44	32	174.4	178.6	182.6	186.4	190.0	193.4	196.7	199.9	204.0	207.0	209.9	212.7	215.2	44
45	33	171.7	175.9	179.9	183.7	187.3	190.7	194.0	197.2	201.3	204.3	207.2	210.0	212.5	45
46	33.25-28° B	170.8	175.0	179.0	182.8	186.4	189.8	193.1	196.3	200.4	203.4	206.3	209.1	211.6	46
47	34	168.9	173.1	177.1	180.9	184.5	187.9	191.2	195.4	198.5	201.5	204.4	207.2	209.7	47
48	35	166.3	170.5	174.5	178.3	181.9	185.3	188.6	192.8	195.9	198.9	201.8	204.6	207.1	48

The figures in the top row indicate gauge pressures, while those in the columns beneath give the temperatures in degrees, Fahrenheit, of the gas at the gauge pressures indicated at the head of each column, thus: Under gauge pressure 75 (pounds) the temperature of the gas of 26-degree ammonia is 189.6 degrees Fahrenheit.

PROPERTIES OF AMMONIA LIQUID—Continued
(Starr's Table)

Relation Between Pressure and Temperature for Solutions of Ammonia in Water of Different Strengths

Line	Per Cent. of NH_3 by Weight and Degree Beaumé	130	135	140	145	150	155	160	165	170	175	180	Line
1	1	348.8	351.3	353.7	356.0	358.2	360.3	362.3	364.2	366.1	367.4	369.5	1
2	1.84-11°B	344.4	346.9	349.3	351.6	353.8	355.9	357.9	359.9	361.7	363.5	365.1	2
3	2	343.6	346.1	348.2	350.8	352.9	355.1	357.1	358.9	360.9	362.7	364.3	3
4	3	338.3	340.8	342.9	345.5	347.6	349.8	351.8	353.6	355.6	357.4	359.0	4
5	3.80-12°B	333.7	336.2	338.6	340.9	343.1	345.2	347.2	349.2	351.1	352.8	354.4	5
6	4	332.6	335.2	337.6	339.8	342.1	344.1	346.2	348.2	350.1	351.7	353.4	6
7	5	327.3	329.9	332.3	334.5	336.8	338.8	340.9	342.9	344.9	346.4	348.1	7
8	5.30-13°B	325.9	328.4	330.8	333.1	335.3	337.4	339.4	341.3	343.2	345.0	346.6	8
9	6	322.4	324.8	327.3	329.5	331.8	333.8	335.9	337.7	339.6	341.4	343.7	9
10	6.80-14°B	317.8	320.3	322.7	325.0	327.2	329.3	331.3	333.3	335.2	336.9	338.5	10
11	7	316.9	319.3	321.8	324.0	321.3	328.3	330.4	332.3	334.1	335.9	336.6	11
12	8	312.0	314.3	316.9	319.1	321.4	327.3	325.5	327.4	329.2	330.9	331.7	12
13	8.22-15°B	309.8	312.3	314.7	317.0	319.2	321.3	323.3	325.3	327.2	328.9	330.5	13
14	9	306.4	308.9	311.3	313.6	315.8	317.9	319.9	321.8	323.7	325.5	327.2	14
15	10-16°B	301.1	303.6	306.0	308.3	310.5	312.6	314.6	316.6	318.5	320.2	321.8	15
16	11	296.6	299.2	301.5	303.8	305.0	308.2	310.2	312.1	314.0	315.8	317.5	16
17	12	292.1	294.7	297.0	299.3	300.5	303.8	305.8	307.6	309.5	311.3	313.0	17
18	12.17°B	290.1	292.6	295.0	297.3	299.5	301.6	303.6	305.6	307.5	309.2	310.8	18
19	13	286.5	289.1	291.5	293.7	296.0	298.1	300.1	302.0	304.0	305.7	307.3	19
20	13.88-18°B	282.9	285.4	287.8	290.1	292.3	294.4	296.4	298.3	300.1	302.0	303.6	20
21	14	282.4	284.9	287.3	289.6	291.8	293.9	295.9	297.8	299.6	301.5	303.1	21
22	15	278.2	280.7	283.1	285.4	287.6	289.7	291.7	293.6	295.4	297.3	298.9	22
23	16	274.0	276.5	279.9	281.2	283.4	285.5	287.5	289.4	291.3	293.1	294.7	23
24	16.22-19°B	272.8	275.3	277.7	280.0	282.2	284.3	286.3	288.3	290.3	292.0	293.6	24
25	17	269.6	272.1	274.5	276.8	278.0	281.1	283.1	285.1	287.1	288.8	290.4	25
26	18.03-20°B	265.2	267.7	270.1	272.4	274.6	276.7	278.7	280.7	282.6	284.3	285.9	26
27	19	261.2	263.8	266.1	268.5	270.6	272.8	274.7	276.8	278.6	280.4	282.0	27
28	19.87-21°B	258.0	260.5	262.9	265.2	267.4	269.5	271.5	273.5	275.4	277.1	278.7	28
29	20	257.5	260.1	262.4	264.7	266.9	269.0	271.1	273.0	275.0	276.6	278.2	29
30	21	253.8	256.4	259.7	261.0	263.2	265.3	267.4	269.3	271.3	272.9	274.5	30
31	21.75-22°B	250.8	253.3	255.7	258.0	260.2	262.3	264.3	266.3	268.2	269.9	271.5	31
32	22	249.9	252.4	254.8	257.1	259.3	261.4	263.4	265.4	267.3	269.0	270.6	32
33	23.03-23°B	245.7	248.2	250.6	252.9	255.1	257.2	259.2	261.2	263.1	264.8	266.4	33
34	24	242.6	246.0	247.4	249.7	251.9	254.0	256.0	257.9	259.8	261.5	263.1	34
35	24.99-24°B	238.9	241.4	243.8	246.1	248.3	250.4	252.4	254.4	256.3	258.0	259.6	35
36	26	235.8	238.3	240.6	242.9	245.2	247.3	249.3	251.2	253.1	254.9	256.5	36
37	27	232.6	235.2	237.4	239.8	242.1	244.2	246.1	248.0	249.9	251.7	253.4	37
38	27.66-25°B	230.0	232.5	234.9	237.2	239.4	241.5	243.5	245.3	247.2	248.9	250.5	38
39	28	229.0	231.4	233.9	236.1	238.4	240.4	242.5	244.3	246.1	247.8	246.5	39
40	29	225.9	228.4	230.8	233.0	235.4	237.3	239.4	241.3	243.1	244.8	245.5	40
41	29.60-26°B	223.8	226.3	228.7	231.0	233.2	235.3	237.3	239.3	241.2	242.9	244.5	41
42	30	222.6	225.1	227.5	229.8	232.0	234.1	236.1	238.1	240.0	241.7	243.3	42
43	31.05-27°B	220.4	222.9	225.3	227.6	229.8	231.9	233.9	235.8	237.5	239.2	240.8	43
44	32	217.8	220.3	222.7	225.0	227.2	229.3	231.3	233.2	234.9	236.5	238.2	44
45	33	215.1	217.6	220.0	222.7	224.5	226.6	228.6	230.5	232.2	233.8	235.5	45
46	33.25-28°B	214.2	216.7	219.1	221.8	223.6	225.6	227.5	229.3	231.1	234.8	234.4	46
47	34	212.3	214.8	217.2	219.9	221.7	223.7	225.6	227.4	229.2	230.9	232.5	47
48	35	209.7	212.2	214.6	217.3	219.1	221.1	223.8	224.8	226.8	228.2	231.3	48

The figures in the top row indicate gauge pressures, while those in the columns beneath give the temperatures in degrees, Fahrenheit, of the gas at the gauge pressures indicated at the head of each column, thus: Under gauge pressure 145 (pounds) the temperature of the gas of 26-degree ammonia is 231.0 degrees, Fahrenheit.

TABLE OF CHLORIDE OF CALCIUM SOLUTION

Specific Gravity at 64 Degrees F.	Degree Beaumé at 64 Degrees F.	Degree Salometer at 64 Degrees F.	Per Cent of CaC12	Freezing Point in Degrees F.	Ammonia Gauge Pressure Pounds per Square Inch
1.007	1	4	0.943	+31.20	48
1.014	2	8	1.886	+30.40	45
1.021	3	12	2.829	+29.60	44
1.028	4	16	3.772	+28.80	43
1.035	5	20	4.715	+28.00	42
1.043	6	24	5.658	+26.89	41
1.050	7	28	6.601	+25.78	40
1.058	8	32	7.544	+24.67	38
1.065	9	36	8.487	+23.56	37
1.073	10	40	9.430	+22.09	35.5
1.081	11	44	10.373	+20.62	34
1.089	12	48	11.316	+19.14	32.5
1.097	13	52	12.259	+17.67	30.5
1.105	14	56	13.202	+15.75	29
1.114	15	60	14.145	+13.82	27
1.122	16	64	15.088	+11.89	25
1.131	17	68	16.031	+ 9.96	23.5
1.140	18	72	16.974	+ 7.68	21.5
1.149	19	76	17.917	+ 5.40	20
1.158	20	80	18.860	+ 3.12	18
1.167	21	84	19.803	— 0.84	15
1.176	22	88	20.746	— 4.44	12.5
1.186	23	92	21.689	— 8.03	10.5
1.196	24	96	22.632	—11.63	8
1.205	25	100	23.575	—15.23	6
1.215	26	104	24.518	—19.56	4
1.225	27	108	25.461	—24.43	1.5
1.236	28	112	26.404	—29.29	1″ vacuum
1.246	29	116	27.347	—35.30	5″ vacuum
1.257	30	120	28.290	—41.32	8.5″ vacuum
1.268	31	......	29.233	—47.66	12″ vacuum
1.279	32	......	30.176	—54.00	15″ vacuum
1.290	33	......	31.119	—44.32	10″ vacuum
1.302	34	......	32.062	—34.66	4″ vacuum
1.313	35	......	33.	—25.00	1.5 pounds

TABLE OF BRINE SOLUTION

(Chloride of Sodium—Common Salt)

Percentage of Salt by Weight	Deg. on Salometer at 60 Deg. F.	Spec. Grav. at 60 Deg. F.	Specific Heat	Weight of One Gallon	Pounds of Salt in One Gallon	Pounds of Water in One Gallon	Weight of One Cu. Ft.	Pounds of Salt in One Cu. Ft.	Pounds of Water in One Cu. Ft.	Freezing Point Deg. F.
0	0	1.	1	8.35	0.	8.35	62.4	0.	62.4	32.
1	4	1.007	0.992	8.4	0.084	8.316	62.8	0.628	62.172	31.8
5	20	1.037	0.96	8.65	0.432	8.218	64.7	3.237	61.465	25.4
10	40	1.073	0.892	8.95	0.895	8.055	66.95	6.695	60.253	18.6
15	60	1.115	0.885	9.3	1.395	7.905	69.57	10.435	59.134	12.2
20	80	1.150	0.829	9.6	1.92	7.68	71.76	14.352	57.408	6.86
25	100	1.191	0.783	9.94	2.485	7.455	74.26	18.565	55.695	1.00

AQUA AMMONIA

Be°	Sp. Gr.	$\%NH^3$	Be°	SP. Gr.	$\%NH^3$	Be°	Sp. Gr.	$\%NH^3$
10.00	1.0000	.00	16.50	.9556	11.18	23.00	.9150	23.52
10.25	.9982	.40	16.75	.9540	11.64	23.25	.9135	24.01
10.50	.9964	.80	17.00	.9524	12.10	23.50	.9121	24.50
10.75	.9947	1.21	17.25	.9508	12.56	23.75	.9106	24.99
11.00	.9929	1.62	17.50	.9492	13.02	24.00	.9091	25.48
11.25	.9912	2.04	17.75	.9475	13.49	24.25	.9076	25.97
11.50	.9894	2.46	18.00	.9459	13.96	24.50	.9061	26.46
11.75	.9876	2.88	18.25	.9444	14.43	24.75	.9047	26.96
12.00	.9859	3.30	18.50	.9428	14.90	25.00	.9032	27.44
12.25	.9842	3.73	18.75	.9412	15.37	25.25	.9018	27.93
12.50	.9825	4.16	19.00	.9396	15.84	25.50	.9003	28.42
12.75	.9807	4.59	19.25	.9380	16.32	25.75	.8989	28.91
13.00	.9790	5.02	19.50	.9365	16.80	26.00	.8974	29.40
13.25	.9773	5.45	19.75	.9349	17.28	26.25	.8960	29.89
13.50	.9756	5.88	20.00	.9333	17.76	26.50	.8946	30.38
13.75	.9739	6.31	20.25	.9318	18.24	26.75	.8931	30.87
14.00	.9722	6.74	20.50	.9302	18.72	27.00	.8917	31.36
14.25	.9705	7.17	20.75	.9287	19.20	27.25	.8903	31.85
14.50	.9689	7.61	21.00	.9272	19.68	27.50	.8889	32.34
14.75	.9672	8.05	21.25	.9256	20.16	27.75	.8875	32.83
15.00	.9655	8.49	21.50	.9241	20.64	28.00	.8861	33.32
15.25	.9639	8.93	21.75	.9226	21.12	28.25	.8847	33.81
15.50	.9622	9.38	22.00	.9211	21.60	28.50	.8833	34.30
15.75	.9605	9.83	22.25	.9195	22.08	28.75	.8819	34.79
16.00	.9589	10.28	22.50	.9180	22.56	29.00	.8805	35.28
16.25	.9573	10.73	22.75	.9165	23.04			

Specific Gravity determinations were made at 60°F., compared with water at 60°F.
From the Specific Gravities the corresponding degrees Beaumé were calculated by the following formula:

$$\text{Beaumé} = \frac{140}{\text{Sp. Gr.}} - 130.$$

Above table adopted as a standard by the Manufacturing Chemists' Association of the United States.

SPECIFIC AND LATENT HEAT OF VARIOUS FOOD PRODUCTS

Substance	Composition		Specific Heat Above Freezing in Heat Units	Specific Heat Below Freezing in Heat Units	Latent Heat of Freezing in Heat Units
	Water	Solids			
Lean Beef	72.00	28.00	0.77	0.41	102
Fat Beef	51.00	49.00	.60	.34	72
Veal	63.00	37.00	.70	.39	90
Fat Pork	39.00	61.00	.51	.30	55
Eggs	70.00	30.00	.76	.40	100
Potatoes	74.00	26.00	.80	.42	105
Cabbage	91.00	9.00	.93	.48	129
Carrots	83.00	17.00	.87	.45	118
Milk	87.50	12.50	.90	.47	124
Oysters	80.38	19.62	.84	.44	114
Whitefish	78.00	22.00	.82	.43	111
Eels	62.07	37.93	.69	.38	88
Lobster	76.62	23.38	.81	.42	108
Pigeon	72.40	27.60	.78	.41	102
Chicken	73.70	26.30	.80	.42	105

The figures in the last column showing the latent heat of freezing have been obtained by multiplying the latent heat of freezing water, which is 142 heat units, by the per cent of water contained in the different materials considered, for as the solid constituents remain in their original condition, only the liquid or watery portion of these materials are concerned in the solidification or free.ing of them.

Table Showing Refrigerating Effect of One Cubic Foot of Ammonia Gas at Different Condenser and Suction (Back) Pressures in B. T. Units

Temperatures of Gas in Degrees F.	Corresponding Suction Pressure Pounds per Square Inch	Temperature of the Liquid in Degrees F.								
		65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (Gauge), Pounds per Square Inch								
		103	115	127	139	153	168	184	200	218
	G. Pres.									
—27	1	36.36	36.48	36.10	35.72	35.34	34.96	34.58	34.20	33.82
—20	4	27.30	27.01	26.73	26.44	26.16	25.87	25.59	25.30	25.02
—15	6	33.74	33.40	33.04	32.70	32.34	31.99	31.64	31.30	30.94
—10	9	42.28	41.84	41.41	40.97	40.54	40.10	39.67	39.23	38.80
— 5	13	48.31	47.81	47.32	46.82	46.33	45.83	45.34	44.84	44.35
— 0	16	54.88	54.32	53.76	53.20	52.64	52.08	51.52	50.96	50.40
5	20	61.50	60.87	60.25	59.62	59.00	58.37	57.75	57.12	56.50
10	24	68.66	67.97	67.27	66.58	65.88	65.19	64.49	63.80	63.10
15	28	75.88	75.12	74.35	73.59	72.82	72.06	71.29	70.53	69.76
20	33	85.15	84.30	83.44	82.59	81.73	80.88	80.02	79.17	78.31
25	39	95.50	94.54	93.59	92.63	91.68	90.72	89.97	88.81	87.86
30	45	106.21	105.15	103.09	102.03	101.97	100.91	99.85	98.79	97.73
35	51	115.69	114.54	123.39	112.24	111.09	109.94	108.79	107.64	106.49

Table Giving Number of Cubic Feet of Gas That Must Be Pumped per Minute at Different Condenser and Suction Pressures to Produce 1 Ton of Refrigeration in 24 Hours

Temperatures of Gas in Degrees F.	Corresponding Suction Pressure Pounds per Square Inch	Temperature of the Gas in Degrees F.								
		65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (Gauge), Pounds per Square Inch								
		103	115	127	139	153	168	184	200	218
	G. Pres.									
—27	1	7.22	7.3	7.37	7.46	7.54	7.62	7.70	7.79	7.88
—20	4	5.84	5.9	5.96	6.03	6.09	6.16	6.23	6.30	6.43
—15	6	5.35	5.4	5.46	5.52	5.58	5.64	5.70	5.77	5.83
—10	9	4.66	4.73	4.76	4.81	4.86	4.91	4.97	5.05	5.08
— 5	13	4.09	4.12	4.17	4.21	4.25	4.30	4.35	4.40	4.44
0	16	3.59	3.63	3.66	3.70	3.74	3.78	3.83	3.87	3.91
5	20	3.20	3.24	3.27	3.30	3.34	3.38	3.41	3.45	3.49
10	24	2.87	2.9	2.93	2.96	2.99	3.02	3.06	3.09	3.12
15	28	2.59	2.61	2.65	2.68	2.71	2.73	2.76	2.80	2.82
20	33	2.31	2.34	2.36	2.38	2.41	2.44	2.46	2.49	2.51
25	39	2.06	2.08	2.10	2.12	2.15	2.17	2.20	2.22	2.24
30	45	1.85	1.87	1.89	1.91	1.93	1.95	1.97	2.00	2.01
35	51	1.70	1.72	1.74	1.76	1.77	1.79	1.81	1.83	1.85

PIPING OF COLD STORAGE ROOMS

2-Inch Direct Expansion Ammonia Piping — Table No. 1
R = No. of Cubic Feet Allowed per Lineal Foot of Pipe

Minimum Temperature of Room	Approximate Evaporation (Suction) Ammo. Press.	SIZE OF ROOM			Unit Heat Leakage
		3,000 Cu. Ft. Capacity	10,000 Cu. Ft. Capacity	25,000 Cu. Ft. Capacity	
0° F.	8 lbs. Gauge	R= 4. —1	R= 5. —1	R= 6.—1	1.0 B.T.U.
5° F.	10 " "	5. —1	7. —1	9.—1	1.2 "
10° F.	12 " "	6.5—1	9. —1	12.—1	1.3 "
15° F.	14 " "	8. —1	11.5—1	15.—1	1.4 "
20 °F.	16 " "	10. —1	14. —1	18.—1	1.5 "
25° F.	18 " "	12. —1	16.5—1	21.—1	1.6 "
28° F.	18 " "	14. —1	19. —1	24.—1	1.7 "
32° F.	22 " "	16. —1	21.5—1	27.—1	1.8 "
35° F.	24 " "	18. —1	24. —1	30.—1	2.0 "

$1\frac{1}{4}$-inch Brine Piping — Table No. 2
R = No. of Cubic Feet Allowed per Lineal Foot of Pipe

Minimum Temperature of Room	Maximum Temperature Brine	SIZE OF ROOM			Unit Heat Leakage
		3,000 Cu. Ft. Capacity	10,000 Cu. Ft. Capacity	25,000 Cu. Ft. Capacity	
0° F.	—7.° F.	R=2. —1	R= 3. —1	R= 4. —1	1.0 B.T.U.
5° F.	—2.° F.	2.5—1	4. —1	5. —1	1.2 "
10° F.	+2.5° F.	3. —1	5. —1	6. —1	1.3 "
15° F.	+6.° F.	4. —1	6. —1	7.5—1	1.4 "
20° F.	9.° F.	5. —1	7. —1	9. —1	1.5 "
25° F.	12.° F.	6. —1	8. —1	10.5—1	1.6 "
28° F.	14.° F.	7. —1	9.5—1	12. —1	1.7 "
32° F.	16.° F.	8. —1	10.5—1	13.5—1	1.8 "
35° F.	18.° F.	9. —1	12. —1	15. —1	2.0 "

Notes

(1) Unit Heat Leakage is the transmission in B. T. U. per square foot per degree F. difference in temperature for 24 hours.

(2) The above Pipe Ratios provide not only for the heat leakage as noted, but also for an additional 25% (approx.) refrigerating duty.

(3) If the daily cooling of fresh goods exceeds this amount, then additional pipe surface should be provided.

(4) For Ice Storage Rooms allow 20% (approx.) less pipe than tabulated above, or Ice Storage Ratio $= \dfrac{\text{Standard Ratio}}{.80}$

(5) Range of Brine Temperature = 3° for 0° Rooms, and 5° for 35° Rooms.

(6) $\dfrac{\text{Temperature Range in Degrees Fahrenheit}}{} \times \text{Gallons brine per minute per ton of Refrigeration} = 28$ approx. for Calcium Brine.

Thus— for 3° range, $\dfrac{28}{3} = 9\frac{1}{3}$ gallons.

PIPING RATIOS FOR COLD STORAGE ROOMS

No hard and fast rule can be laid down for the amount of piping necessary in a cold storage room to maintain a certain temperature, as there are too many variable quantities to be considered.

Pipe surface, in any case, may be found from the following formula:

$$S = \frac{W}{R \times D}, \text{ in which}$$

S = Square Feet of Pipe Surface.

W = Work or Refrigerating Duty expressed in B. T. U. for one hour.

R = Rate of Heat Transfer per square foot of Pipe Surface per hour for every degree of mean difference.

D = Mean Difference, or Difference between average temperature of cooling medium and average temperature of air in the room.

W or Work is dependent in all cases upon the character of the insulation, the exposure to or protection from high temperature, heat introduced by opening of doors, from electric lights, human bodies, etc.

In many cases the substances in storage are received and removed daily, so additional refrigeration must be allowed for actual work upon the goods stored.

R or Rate of Heat Transfer, while practically constant, is dependent somewhat upon the natural air circulation, which in turn is dependent upon the Mean Difference.

D or Mean Difference has a most decided bearing on the surface required. It can be readily seen from the formula that with a fixed Surface and a practically constant Rate of Heat Transfer, the **Work** is in direct proportion to the Mean Difference. If the work is increased, the Mean Difference must be increased, in order to maintain a constant Temperature.

Likewise, if the **Work** is constant, and Mean Difference is increased, the Surface required will decrease. Hence, in the tables on the opposite page, the Surface will decrease and the Pipe Ratio increase in proportion to increase in Mean Difference.

For example—(Refer to Table No. 1.)

28° F. Room, 20 lbs. Suction Gauge Pressure R=14—1

Corresponding Temperature for 20 lbs. Suction Gauge Pressure 6° F.

28°—6°=22° M. D.

For 15.7 lbs. Suction Gauge Pressure, Corresponding Temperature=0° F.

28°—0°=28° M. D.

$$\text{Then Ratio} = \frac{28 \times 14}{22} = 17.8 — 1$$

In the following tables we have assumed that first-class insulation and special cold storage doors are used, with a unit heat leakage not greater than 1.0 B.T.U. for 0° rooms, and 2.0 B.T.U. for 35° rooms.

COLD STORAGE TEMPERATURES

Articles	Degrees Fahrenheit	Articles	Degrees Fahrenheit
Fruits		**Liquids**	
Apples	32–36	Beer, Ale, Porter, etc.	33
Bananas	34	Cider	30
Berries, fresh	36	Ginger Ale	36
Cranberries	33–36	Wines	40–45
Cantaloupes	40		
Dates, Figs, etc.	50–55	**Flour and Meal**	
Fruits, dried	35–40		
Grapes	34–36	Buckwheat Flour	36–40
Lemons	33–36	Corn Meal	36–40
Oranges	34 36	Oat Meal	36–40
Peaches	34–36	Wheat Flour	36–40
Pears, Watermelons	34–36		
Meats		**Vegetables**	
Brined	38	Asparagus	34–35
Beef, fresh	33	Cabbage	34–35
Beef, dried	36–40	Carrots	34–35
Calves	32–33	Celery	34–35
Hams, Ribs, Shoulders (not brined)	20	Dried Beans	32–40
Hogs	29–32	Dried Corn	35
Lard	38	Dried Peas	35–40
Livers	20–30	Onions	36
Sheep, Lambs	32	Parsnips	34–35
Ox-tails	30	Potatoes	36–40
Sausage Casings	20	Sauerkraut	35
Tenderloins, Butts, etc.	33		
Fish		**Miscellaneous**	
Fresh Fish	20	Cigars, Tobacco	35
Dried Fish	36	Furs, Woolens, etc.	35
Oysters in shell	30–35	Honey	45
Oysters in tubs	25	Hops	40
Canned Goods		Maple Syrup, Sugar	40–45
		Oils	35
Sardines	35–40	Poultry, dressed, iced	28–30
Fruits	35–40	Poultry, dry picked	26–28
Meats	35–40	Poultry, scalded	20
Butter, Eggs, Etc.		Game, to freeze	15–18
		Game, after frozen	25–28
Butter	18–20	Poultry, to freeze	15–18
Butterine	18–20	Poultry, after frozen	25–28
Cheese	34	Nuts, in shell	35–40
Eggs	31	Chestnuts	33

AIR
COMPRESSION

AIR COMPRESSORS

According to the well known law of the Conservation of Energy, energy cannot be destroyed. Mechanical energy may be converted to heat energy, heat energy may be converted to electric energy, et cetera, but, nevertheless, the same quantity of energy exists as existed before.

In the case of compressing air in an air compressor, all the mechanical energy is entirely converted into heat energy, part in the form of friction of the compressor, but by far the larger part in compressing the air which is heated.

If the ideal cooling devices could be used and the heat due to the compressing of the air could be be removed from the compressed air, then we have the air at the same temperature as it was before being compressed. Now, as all the mechanical energy was converted into heat energy which has been carried away by cooling devices, it would appear at first thought as if nothing had been gained. In a sense this is true, but the advantage of the compression lies in bringing its energy into a more available form.

This can be better understood by taking the analogy of two ponds of water of equal size, one on the top of a hill and the other at the bottom. So long as the water in each is contained within its banks, conditions are equal, but the position of the water in the upper pond brings its energy into an available form.

Air, like other substances, expands when heated and contracts when cooled, and the greatest loss in air compressors is due to this fact. The air is heated in the compressor cylinder with the result that the compressor is discharging air of an expended nature which contracts when cooled. The compressor is therefore always working against a higher back pressure than would be necessary if the air did not expand, or, to express it another way, the compressor must pump a larger volume of air than the volume of air afterwards available to do work.

It can be seen that the cooler the air is kept during compression the less power will be required. This is accomplished, to a certain extent, by having the cylinders water jacketed, and also having the air pass through a cooler before going to the receiving tank.

A further saving in this respect, can be obtained by using a compound cylinder compressor with an inter-cooler situated between the two compressors. The air, after leaving the low pressure cylinder passes through the cooler, where a considerable portion of the heat is extracted before reaching the high pressure cylinder.

Why Air Drills Freeze

It is a well known fact that trouble is experienced in air drills, that the moisture in the compressed air will freeze, giving trouble in the operation of the machine. The question may be asked, what is the cause of this? As already explained, the heat energy in the compressed air has been removed by the cooling water. Now, when we come to use this air, we have air at the same temperature as the atmosphere, where this air goes after doing work.

In passing through the drill the air does work using mechanical energy, but mechanical energy cannot be produced except at the expense of an equal amount of energy in some other form, such as heat. The air in the drill is expending mechanical energy and must grasp energy in some other form to replace it, which it does by seizing heat energy from all surrounding substances nearest at hand, with the result that the water in the air is robbed of a part of its heat (mostly latent heat) and turned to ice.

Refrigeration by Compressed Air

Cold air refrigeration was based on the principle outlined in the preceding paragraph.

It was commonly used on ocean-going vessels in the past, although it is now almost entirely superseded by carbon dioxide compressors, which are not so large and cumbersome.

The warm air was drawn from the chilling room. It was then compressed and cooled by water circulating through pipes. The cooled air was then passed into a cylinder fitted like an ordinary slide valve engine.

The air expanding drove the piston forward and through the connecting rod and crank, helped to drive the compressor. The exhaust air of the engine, having done work in expanding, cooled itself to a low temperature and was led back into the chilling room.

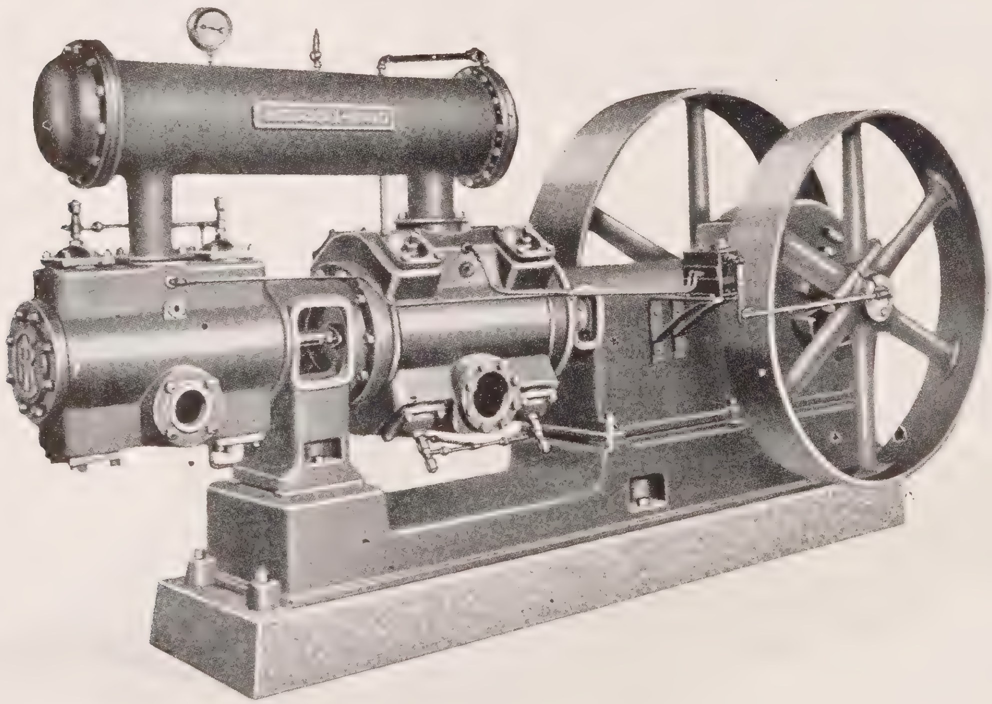


Fig. 36 Tandem compound air compressor.

Compressor Operation

Fig 36 shows a compound compressor with an intercooler on top. Fig. 37 is a cross section showing arrangement of tubes in intercooler. The cylinders are also water jacketed.

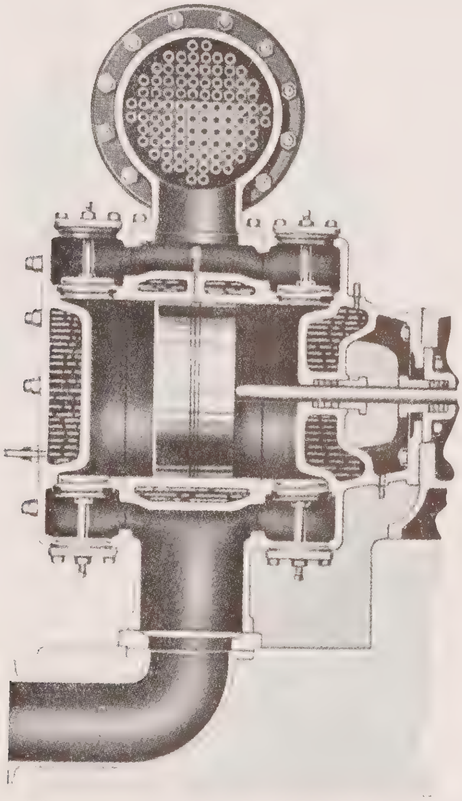


Fig. 37. Cross section of air cylinder and intercooler of air compressor.

Fig. 38 is a diagram of an air receiver and its connection with the compressor.

The discharge from an air compressor is pulsating in character, as an air receiver is a "rectifier", so to speak, which receives and absorbs these pulsations and delivers a steady flow to the pipe line.

It is, in a very small degree, an accumulator in which excess energy is momentarily stored and withdrawn, but it cannot be relied upon as an effective means of power storage in any large degree.

The air receiver cannot be too large, nor can there be too many receivers, provided that leakage is carefully avoided in the connections. Large receiver capacity is especially useful in work of an intermittent character, such as running rock drills, pneumatic tools, et cetera. It makes problems of regulation easier and assists the governor or regulator of the compressor in maintaining a steady pressure.

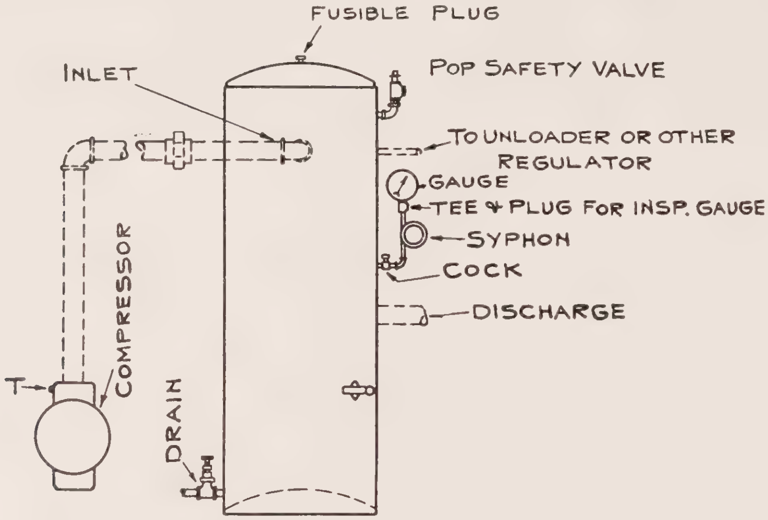


Fig. 38. Diagram illustrating method of connecting air receivers.

Air Tank Construction

The Interprovincial Regulations (in part) give the following rules regarding air tanks:

Minimum Thickness of Plate of Compressed Air and Gas Tanks

The thickness of shell plates of compressed air and gas tanks over 24 inches in diameter shall not be less than the minimum thickness for a steam boiler and of equal diameter.

Maximum Working Pressure Allowable on Cylindrical Shells

The maximum working pressure to be allowed on the cylindrical shell of a tank or receptacle for compressed air or gas shall be determined by the formulae in Sections 193 to 197 of Part 1, of these Regulations, except that the basic factor of safety as provided in Section 197, shall be $3\frac{1}{2}$ for tanks or receptacles being under inspection and 4 for tanks or receptacles not built under inspection, with additions to the basic factor of safety as provided for in the aforesaid Section.

Welded Joints

The efficiency of the longitudinal of a shell or drum when welded by the forging process shall be taken at not more than 50 per cent of the solid plate for butt-welded joints, and 60 per cent of the solid plate for lap-welded joints, when calculating the maximum working pressure allowable by the formula in Section 193 of these Regulations.

Brazed or Welded Joints

Air or gas pressure tanks having the longitudinal seam welded by acetylene or electric welding process or brazed only without being riveted will not be allowed for working pressures exceeding 75 pounds per square inch, for air-pressure tanks where the shell plate

is less than $\frac{1}{4}$ inch in thickness, the longitudinal seam may be riveted and then brazed, the efficiency of the riveted joint being calculated by the formulae in sections 203 and 207 with the addition of 15 per cent efficiency for the value of resistance of the brazing. The efficiency in no case shall be taken at more than 50 per cent of the solid plate for single riveting and 70 per cent for double riveting.

The heads may be welded or brazed to the shell, provided that the heads are stayed with sufficient stays to carry the whole load on the head, or the ends of the shell may be turned over the flange of the head and then welded or brazed.

Safety Valves

Every air compressor system shall have one or more safety valves of the direct spring loaded type of approved design which should be installed on the discharge pipe as near the compressor cylinder as practicable. When the safety valve is located on the tank, the area shall not be less than the area of the intake opening to the tank and where the safety valve is located on the discharge line the discharge capacity of the safety valve or valves shall be sufficient to discharge all the air which can be delivered by the air compressor at its maximum speed with all outlets from the tank shut off. If the accumulated pressure exceeds six per cent of the maximum allowable working pressure of the tank or reservoir, additional safety valve capacity must be provided.

Safety valves installed on air compressor systems shall not exceed three inches in diameter and shall be provided with a substantial lifting device. The disc seat shall be of non-ferrous material.

Safety valves exposed to a temperature of 32 degrees Fahrenheit or less shall be provided with a drain not less than three-eighths inch diameter at the lowest point at which water can collect.

Safety Valve Connections

Safety valves shall have full size connections to the compressor system, and no valve of any description shall be placed between the safety valve and the compressor. Where two or more safety valves are placed on one connection the cross sectional area of the connection shall be equal to or greater than the combined area of the valves.

When escape pipes are fitted they shall be of full size and be provided with an open drain to prevent water lodging above the valve. No valve shall be placed on the escape pipe between the safety valve and the atmosphere.

Fusible Plug

Every air pressure tank or receptacle carrying a pressure of over 75 pounds per square inch which receives air directly from an air compressor without any intervening tank, shall be provided with an approved fusible plug which shall be filled with a fusible metal melting at a temperature of not more than 450 degrees Fahrenheit. The fusible plug shall be placed at the highest point of the tank.

Suitable fusible plugs or safety disc shall be fitted to all gas pressure tanks.

Pressure Gauge

Every air compressor system shall be provided with an approved pressure gauge, which shall be connected by a syphon or similar device sufficiently large to fill the gauge tube with water. A cut-out cock with a T or lever handle shall be placed between the syphon and the connection to the tank or discharge pipe of the compressor.

Inspectors' Test Gauge Connection

A one-quarter inch pipe size connection shall be provided to permit the inspector's gauge to be connected above the cock or syphon pipe for the purpose of testing the accuracy of the pressure gauge.

Drain Pipe

Every air pressure tank shall be provided with a drain pipe not less than half-inch diameter for air pressure tanks having a capacity of 10 cubic feet or less and three-quarter-inch diameter for larger tanks. The drain pipe shall be fitted with a gate valve or cock. Glove valves shall not be used for this purpose.

Air pressure tanks shall be thoroughly drained of all accumulations of water and oil at least once in each working day.

Maximum Pressure

The maximum pressure allowed on any tank of a compressed air system, excepting intercoolers, shall not exceed the lowest allowable pressure on any tank in the said system, unless a reducing valve is provided, together with a safety valve the full size of the inlet pipe, to the tank having the lower allowable working pressure. The safety valve is to be attached between the reducing valve and the tank having the lower allowable working pressure.

The tank or tanks carrying the lower pressure must be provided with a separate pressure gauge.

Hydrostatic Tests

All air pressure tanks used for working pressure less than 500 pounds per square inch shall be tested by hydrostatic test pressure of one and one-half times the maximum allowable working pressure.

For tanks having a working pressure of 600 pounds per square inch and upwards the hydrostatic test pressure shall be one and one-third times the maximum allowable working pressure.

Constant Speed Unloader

If a compressor is driven at a constant speed, as is generally done when motor driven, and the demand for air is intermittent, it can be seen that a pressure would build up in the receiver.

The compressor would continue to work at full load causing waste of energy through

loss of compressed air through the safety valve. To overcome this, several devices known as unloaders are used.

Fig. 39 shows one type known as the free unloader.

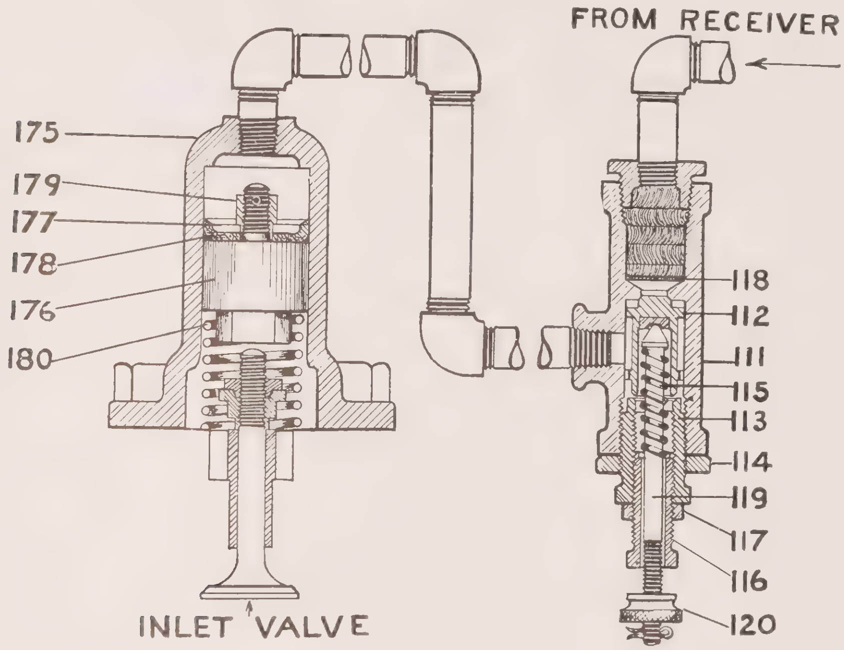


Fig. 39. Constant speed unloader and auxiliary valve used with air compressors.

This unloader controls the unloading of the compressor by opening the air inlet valve when the receiver pressure rises above that which the unloader is set to operate. When the receiver pressure has fallen a predetermined amount, the unloader releases the inlet valve and allows the compressor to build up the receiver pressure.

When the air in the receiver reaches the pressure at which the auxiliary valve is set to operate, it overcomes the resistance of spring 115 and throws valve 112 to its lower seat, allowing air to pass by the upper seat. The upper flange which forms a part of valve 112 is slightly smaller in diameter than the bore of the valve chamber and the air flowing around this flange passes through the piping to the top of the unloader plunger 176. The pressure of air from the receiver here exerts sufficient force on the top of the plunger 176 to overcome the resistance of the plunger spring 180, forcing it downward and opening the inlet valve. Thus the inlet valve is held open as long as there is pressure from the receiver on top of the unloader plunger. Spring 180 relieves the plunger 176 from the top of the inlet valve as soon as the air pressure is exhausted from the top of the plunger.

When the receiver pressure has fallen a predetermined amount, spring 115 throws the unloader valve back to its upper seat, shutting off the pressure from the receiver. The

plunger spring 180 then lifts the plunger off the inlet valve and the compressor resumes its work. The air above the plunger passes back, through the piping, exhausting to atmosphere through the opening in the lower end of spring adjuster 116.

Intake Unloader

Another type, known as the intake unloader, is shown in Fig. 40.

This unloader consists of a balanced stop valve on the intake of the compressor, normally held open by a spring. An auxiliary needle valve, normally held closed by a spring, controls admission of air to a piston which operates to close the main balanced stop valve. The air pressure in the receiver is communicated through a small pipe to one side of a diaphragm on the needle valve stem. When the air pressure rises above normal,

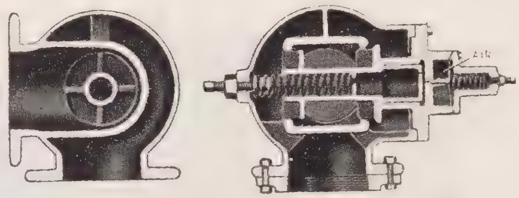


Fig. 40. Another type of constant speed unloader.

the pressure on this diaphragm exceeds the tension of the needle valve spring, opens the needle valve and admits air behind the stop-valve piston. This closes the stop-valve and cuts off the intake to the compressor, thus unloading it. When the air pressure falls to normal, the needle valve closes, cutting off admission of air to the stop-valve piston. This allows the stop-valve to be opened by its springs, opening the intake and throwing the load on the compressor.

Moisture in Air

There is always a considerable amount of water present when air is compressed, which must come from the air.

In air, as we all know, moisture is always present, though in varying amounts, depending on the weather, and it remains in the air as an invisible vapour until the point of saturation or 100 per cent humidity is reached.

This, known as the dew point, is always reached in the compression and transmission of air at the ordinary working pressures, say 6 atmospheres or 75 lb. gauge, and, immediately the point of saturation is passed, the excess moisture condenses into actual visible particles of water, but still mixed with air, the supersaturated air then appearing as a fog or mist. The freed water will slowly settle out of the air if it is quiet long enough.

The saturation point of air constantly varies, and is determined by its pressure and its temperature, especially the latter.

At a fixed temperature, any given volume of air is saturated when it contains a certain definite quantity of water vapour. If the absolute pressure of a certain quantity of air is, say, doubled, by which the volume is reduced one-half, the moisture holding capacity is reduced in the same proportion. Thus, if the humidity of the free air is 50 per cent, this becomes 100 per cent when the air is compressed to 2 atmospheres, or 15 lb. gauge.

Similarly, if it is compressed to 6 atmospheres, 90 lb. absolute, or 75 lb. gauge (a very common working pressure), the humidity becomes 300 per cent—in other words, two-thirds of the moisture will separate as water, and only one-third will be carried as vapour.

It is to be borne in mind that the conditions under which compressed air will have the lowest capacity for holding moisture are high pressure and low temperature. As the air leaves the compressor, and before it begins to be used, it is, of course, at its highest temperature.

In its flow through the pipes, its temperature is reduced, so that when it arrives at the point where its work is to be done, it should be at a low temperature and carry a minimum of moisture, if means have been provided for getting rid of the moisture as it condenses.

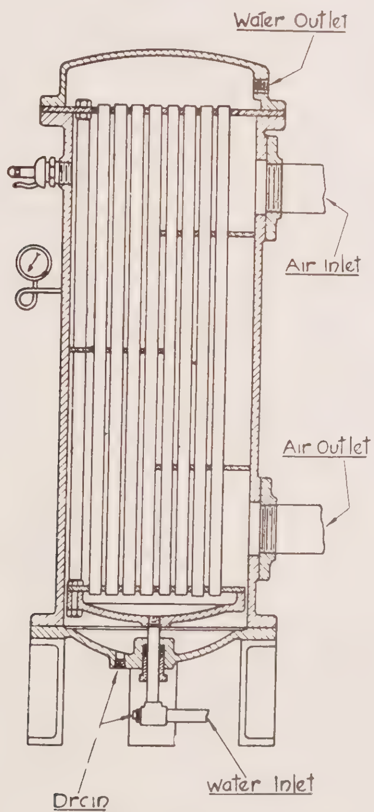


Fig. 41. Cross section of vertical water tube air after-cooler.

By passing the air through an after cooler (see Fig. 41) and reducing its temperature to approximately its initial pre-compression temperature, it is clear that a large percentage of the moisture will be condensed and removed before it can enter the pipe-line, due to the fact that the compressed air has less capacity than the original air for holding moisture.

Cause of Explosions in Air System

In the Union of South Africa there have been sixteen official inquiries by the Department of Mines and Industries, into the circumstances attending explosions among the compressed air system of mines in Transvaal.

Ten of these cases were explosions, while in the other six cases there were only burnings in the pipes or passages, through which the gases passed. Accidents such as the bursting of pipes or receivers, due to inherent weakness or the closing of valves, are not considered.

It is pointed out that the amount of oil used for internal lubrication of the air ends of compressors is not sufficient to form an explosive gaseous mixture, even when lubrication is carried to pronounced excess. Improper lubrication of the air cylinders is, however, the cause of carbonaceous deposits, which are the seat of all trouble.

The use of a very viscous oil results in a greater quantity being required to cover the internal surface of the air cylinder than would be needed if a more fluid oil were employed. Further, owing to its sluggish nature, it collects and amalgamates with particles of dust invariably present in the air being compressed, and rapidly forms into a hard deposit, principally carbon, which clogs the piston rings and valves.

Heavy cylinder oils, because of the viscid nature, encounter difficulty in getting out of the cylinder, thereby being exposed to the drying action of hot compressed air longer than necessary. This results in a heavy deposit of carbon on the valves and in the discharge passages.

These carbonaceous deposits, when in sufficient quantities and in the presence of moisture and heat, are gas producers.

The principal gas formed is carbon monoxide, which ignites at a temperature of 1,204 degrees Fahrenheit. In the absence of the proper degree of heat for ignition, these gases are delivered to the workings.

Neglect to clean intercoolers caused three of the accidents investigated. The hot air leaving the low pressure cylinder carries a small amount of oil vapour in suspension, and this condenses when the air is cooled.

The oil thus carried into the intercooler dries out and leaves a carbon deposit. When not cleaned out this deposit builds up and becomes a source of carbon-monoxide gas.

In five cases, the high-pressure discharge valves were found to be defective or broken. due to carbon deposits. The consequent leakage led to excessive temperatures, which made explosions possible.

Hot air drawn back into the cylinder through a leaky discharge valve and recompressed, is discharged at a higher temperature. It is evident that where the leak is great

enough the temperature will build up to a dangerous point. The higher the speed of the compressor the less the effect of the leak.

Of sixteen accidents, eleven occurred at the time of unloading, generally at the lunch hour. When unloading, there is a much reduced flow of air in the discharge passages. Under certain forms of governing of the compressor, or with leaky high pressure discharge valves, this diminished flow of air will be of a higher temperature, and favorable conditions for spontaneous combustion may thus be established.

As a precaution, it is advisable to periodically clean the compressor system. The compressor can be cleaned by using a solution of soft soap and water, the suds being fed through the lubricator for a few hours and then followed by oil to prevent rusting.

The aftercooler and the receiver can be cleaned by using a solution of lye and water that can be introduced into the discharge pipe by a lubricator or its equivalent, the latter being made of ordinary pipe fittings.

Air Plant Operation

The air receiver or tank should be placed as close to the compressor as possible, so as to keep the discharge pipe short. Never place a valve in the line between compressor and receiver, unless a safety valve is installed between this valve and compressor, as there is a possibility of starting the compressor with this valve closed, in which case, as the air cannot escape, an explosion will result.

If the compressor is to be connected into an air main common to other compressors, see that a safety valve is placed between the compressor and the first valve in the pipe line. This will safeguard the compressor in case of failure to open the valve before starting up.

If the compressor stands near the wall, it is a good plan to place the receiver outside the building where it has an opportunity to radiate some of the heat.

The receiver should be provided with a drain cock near the bottom and should be drained from time to time.

See that the safety valve is in working order and test it occasionally by lifting the lever or raising the pressure to the blowing point.

Be careful to drain the cylinders thoroughly if they are allowed to stand in a freezing temperature, as water freezing in the jacket or heads will certainly crack them sooner or later. Every fall, as soon as cold weather approaches, many cylinders are broken in this manner. All water spaces in heads and jackets should be kept free by washing out as often as found necessary.

Always bear in mind that drainage must be provided for all pipes, receiver and water jackets around cylinder. Use new pipe and fittings for air; lead or oil the joints and screw up tight.

Remember that an air leak is expensive and should not be permitted. A pipe that is perfectly tight for water or steam will also hold air. Let the air pipe line be as large and straight as possible. A little extra care in pipe fitting is labor well spent and will result in long continued economy.

One major cause of loss of efficiency is air leaks—a loss commonly equivalent to a third of the capacity of the compressor.

As a general rule, no attention is paid to small leaks, which are costly and materially lower the efficiency of the plant. For example, a very small hole in a pipe line, a perforation no larger than one made by a common pin, will run into a cost of $60 per year; in other words, it would represent a loss of five cubic feet of air per minute.

The presence of water in compressed air is undesirable and should be eliminated, as it tends to cause freezing, and reduces the effect of the lubricating oil. There is, of course, no such thing as a perfectly dry atmosphere.

The oil level in the crankcase must at all times be so maintained that it is between the high and low level marks on the oil gauge. Never permit the oil level to fall below the low level mark and when replenishing the supply never put in so much that the oil comes above the high level mark. When filling the crankcase for the first time, pour the oil in through the hand holes instead of through the oil filler.

To thoroughly drain and clean the interior of the crankcase, first remove the pipe plug in the opening at the bottom of the crankcase. This will drain out all oil except that in the "constant level" troughs. To clean out this oil, remove the hand hole covers and dip or sponge it out of each trough. Notice the bottom of the crankcase and troughs, and if they are covered with a sludge this should be scraped up and removed, and the crankcase thoroughly flushed out. When refilling the crankcase with oil after cleaning out the constant level troughs, pour the oil in through the hand holes so that there will be oil in both troughs for the first revolution of the oil dippers. Oil can be added through the oil filler when replenishing the supply or after draining out the crankcase when the troughs are not emptied.

Use a good grade of air compressor oil in the compressor crankcase.

When starting up the first time, or after the compressor has been idle for a long period, or after adjustments have been made, run the compressor without load long enough to permit the bearings to become covered with a film of oil.

At regular intervals the main and connecting rod bearings should be inspected for wear. This can be done by removing the hand hole covers on the sides of the cylinder block. If any of the bearings show excessive slack, they must be taken up.

Never run the compressor with a valve which does not operate properly, as it will cause excessive compression temperature. This may result in an explosion in the receiver. Should a valve be taken apart, note carefully the way in which the several parts are arranged so that, in assembling the valve, the proper relation of parts will be kept. Extra caution should be taken to see that the nut is thoroughly tightened and that the cotter pin in the nut is in place.

The inlet and discharge valves are the vital parts of a compressor and should receive careful attention. Clean and inspect these valves at least once a month—more often if found necessary.

Never use kerosene or coal oil in the air chamber to clean out. This is a very dangerous practice and should be prohibited.

If shutdown is to be a long one, it is advisable to remove the packing from the stuffing boxes, as it is liable to corrode and pit the piston rod.

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REFRIGERATION

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AIR COMPRESSION